PB85-115822

Closure Evaluation for Petroleum Residue Land Treatment

Oklahoma Univ., Norman

Prepared for

Robert S. Kerr Environmental Research Lab.
Ada, OK

Oct 84

U.S. Department of Commerce
National Technical Information Service
NTIS

PB85-115822

EPA-600/2-84-162
October 1984

CLOSURE EVALUATION FOR PETROLEUM RESIDUE LAND TREATMENT

by

Leale E. Streebin, James M. Robertson,
Alistaire B. Callender, Lynne Doty,
Kesavalu Bagawandoss
School of Civil Engineering and Environmental Science
University of Oklahoma
Norman, Oklahoma 73019

Cooperative Agreement No. CR 807936010

Project Officer

Don H. Kampbell
Source Management Branch
Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma 74820

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ADA, OKLAHOMA 74820

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

218

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-84-162	2.	3. RECIPIENT'S ACCESSION NO. PB85 115822
4. TITLE AND SUBTITLE Closure Evaluation for Petroleum Residue Land Treatment		5. REPORT DATE October 1984
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) L.E. Streebin, J.M. Robertson, A.B. Callender, L.M. Doty, K. Bagawandoss		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS School of Civil Engineering & Environmental Science University of Oklahoma Norman, OK 73019		10. PROGRAM ELEMENT NO. C73D1C
		11. CONTRACT/GRANT NO. Coop.Agr. CR807936-01-0
12. SPONSORING AGENCY NAME AND ADDRESS R.S. Kerr Environmental Research Laboratory U.S. Environmental Protection Agency P.O. Box 1198 Ada, OK 74820		13. TYPE OF REPORT AND PERIOD COVERED Final 11/80 - 01/83
		14. SPONSORING AGENCY CODE EPA/600/15

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Three refinery land treatment sites which had ceased applications for 6 months, 9 months, and 6 years previously were sampled to define existing conditions. Samples were collected during a 15-month study period. A considerable variation existed in oil content between the 3 sites. Site 2, which had received no waste for 6 years, had 2-3 wt.% oil in the upper 25 cm. Site 1 and 3 contained 5-6 and 8-9 wt.% oil respectively. Concentrations greater than background were detected as deep as 45-50 cm at all sites. Average oil content remained relatively constant at each site during the study. Large variations for individual core samples were found within each site. Possible contributing factors to apparent lack of degradation were long periods of extremely wet or dry soil, low soil N, and presence of persistent hydrocarbons. Thirteen or more organic priority pollutants were identified at each site; however, only trace quantities were found below the till zone. Several priority pollutants also were identified in background samples. Metals were immobilized in top 25 cm of soil at all sites. Site 2 supported a lush growth of vegetation while sites 1 and 3 supported little or no vegetative growth. Grasses were more tolerant than tree seedlings when planted in areas having an oil content of 5-6 wt.%. Root development was inhibited at levels of 4-5 wt.%. In areas having an oil content of 9-13 wt.%, survival rates for both were very low.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Waste treatment Organic wastes Petroleum refining	Solid waste Land treatment Heavy metals Petroleum sludge	13B

18. DISTRIBUTION STATEMENT Release to public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 219
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

NOTICE

Although the research described in this document has been funded wholly or in part by the United States Environmental Protection Agency through assistant agreement number CR 807936010 to The University of Oklahoma, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

FOREWORD

EPA is charged by Congress to protect the Nation's land, air and water systems. Under a mandate of national environmental laws focused on air and water quality, solid waste management and the control of toxic substances, pesticides, noise, and radiation, the Agency strives to formulate and implement actions which lead to a compatible balance between human activities and the ability of natural systems to support and nurture life.

The Robert S. Kerr Environmental Research Laboratory is the Agency's center of expertise for investigation of the soil and subsurface environment. Personnel at the Laboratory are responsible for management of research programs to: (a) determine the fate, transport and transformation rates of pollutants in the soil, the unsaturated zone and the saturated zones of the subsurface environment; (b) define the processes to be used in characterizing the soil and subsurface environment as a receptor of pollutants; (c) develop techniques for predicting the effect of pollutants on ground water, soil and indigenous organisms; and (d) define and demonstrate the applicability and limitations of using natural processes, indigenous to the soil and subsurface environment, for the protection of this resource.

The report, a product of our research, contains information useful to hazardous waste land treatment facilities and regulating agencies on decision making for waste disposal problems. An evaluation of existing conditions at closed oily waste land treatment sites is covered by the topics: (1) degradation of oil, (2) identification and fate of pollutants, and (3) site revegetation.

Clinton W. Hall

Clinton W. Hall
Director
Robert S. Kerr Environmental
Research Laboratory

ABSTRACT

The purpose of the study was to evaluate existing conditions at sites used for the land treatment of oily residues, after closure. Three sites, which had not been used for between 6 months and 6 years, were chosen. No nutrients were added to the site soil, and the sites were tilled 3 or 4 times during the study. Soil samples from these sites were analyzed for oil content, pH, CEC, TOC, chlorides, heavy metals and selected organic priority pollutants. Soil pore water samples and deep core samples were analyzed for heavy metals, oil content and selected priority pollutants. This was done to determine if pollutants were moving into or through the unsaturated zone. Research on methods of revegetating the sites using grasses and trees, was also done at one site.

The soil pore water contained chlorides at concentrations from 12 mg/l to 5000 mg/l, iron, and manganese at concentrations from trace amounts to 12 mg/l, and zinc and barium at levels up to 5 mg/l.

The results show:

(1) no statistically significant degradation of the oil took place over a 15 month period;

(2) organic priority pollutants present at these sites were primarily polynuclear aromatics and phenolics;

(3) metals are generally immobilized in the top 25 cm of soil. However, some metals are mobilized and could present a ground water pollution threat. Analysis of soil pore water and deep core samples indicate

the presence of trace amounts of several organics in the unsaturated zone up to a depth of 150 cm.

Trees generally did not survive at the oil concentrations used (4 to 14%). Grasses grew at soil oil content levels up to 5%, but root development was inhibited at levels of 4 and 5%.

This report was submitted in fulfillment of Cooperative Agreement No. CR 807936010 by the School of Civil Engineering and Environmental Science, University of Oklahoma under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from November 1980 to July 1983, and work was completed as of June 1983.

CONTENTS

Abstract.. iv
Figures.. ix
Tables.. x
Abbreviations and Symbols.......................... xiii
Acknowledgements.. xiv
Section 1 Introduction 1
Section 2 Conclusions.............................. 4
Section 3 Recommendations........................ 7
Section 4 Literature Review...................... 9
Section 5 Site Selection........................ 25
  Site Soil Characteristics............ 28
Section 6 Experimental Approach................. 34
  Sampling Procedures.................. 35
Section 7 Evaluation of Site Characteristics..... 40
  Organics.............................. 40
  Oil Content........................... 43
    Variability of Oil Concentrations.. 44
    Oil Content of Site Soil........... 44
  Metals................................ 52
  Unsaturated Zone Monitoring.......... 58
    Soil Pore Water Analytical Results. 60
    Deep Core Analytical Results....... 78

Preceding page blank

CONTENTS (continued)

Section 8 Emission Study........................ 84

Section 9 Runoff Study......................... 87

Section 10 Revegetation Study..................... 92

Section 11 Discussion............................. 120

References 123

Appendix A Analytical Methods................... 129

Appendix B Site Soil Data....................... 134

Appendix C Concentrations of Organic Compounds Found in Site Soil.................... 164

Quality Assurance/Quality Control... 177

Appendix D Field Data for Trees................. 181

Appendix E Climatological Data.................. 192

Appendix F X-Ray Diffraction Spectra of Site Soil.......................... 195

FIGURES

Figure		Page
6.1	Method of installation of soil pore water samplers...........................	38
7.1	Graph of TOC vs time for site 1 soil moisture samples........................	71
7.2	Graph of TOC vs time for site 2 soil moisture samples........................	72
7.3	Graph of COD vs time for site 2 soil moisture samples........................	73
7.4	Graph of Cl vs time for site 2 soil moisture samples........................	74
7.5	Graph of TOC vs time for site 3 soil moisture samples........................	75
7.6	Graph of COD vs time for site 3 soil moisture samples........................	76
7.7	Graph of Cl vs time for site 3 soil moisture samples........................	77

TABLES

Table 4.1 Toxic Pollutants Detected in Refinery Treated Effluents............. 16

Table 5.1 Site Soil Textural Classification...... 29

Table 5.2 Soil Permeability Values............... 30

Table 5.3 Cation Exchange Capacity of Site Soil.. 33

Table 7.1 Priority Pollutants 41

Table 7.2 Organic Compounds Indentified in Soil at Land Treatment Sites........ 42

Table 7.4 Variability of Oil Concentration at Site 3............................ 45

Table 7.5 Variability of Oil Concentration at Site 2............................ 46

Table 7.6 Oil Content Data - Means Site 1........ 48

Table 7.7 Oil Content Data - Means Site 2........ 48

Table 7.8 Oil Content Data - Means Site 3........ 50

Table 7.9 Composition of Oil at Sites 2 and 3.... 50

Table 7.10 Nitrogen and Phosphorus in Soil at Sites............................. 52

Table 7.11 Metals Found in Concentrations Significantly Above Background......... 54

Table 7.12 Site pH Values........................ 57

Table 7.13 Soil Chloride Concentration............ 57

Table 7.14 Soil TOC.............................. 59

TABLES (continued)

Table 7.15 Priority Pollutants Present in Soil Pore Water........................ 61

Table 7.16 Soil Pore Water Metals (Site 1)........ 62

Table 7.17 Soil Pore Water Metals (Site 2)........ 63

Table 7.18 Soil Pore Water Metals (Site 3)........ 64

Table 7.19 Soil Pore Water Chloride Ion Concentration........................... 66

Table 7.20 Soil Pore Water Characteristics Site 1................................. 68

Table 7.21 Soil Pore Water Characteristics Site 2................................. 69

Table 7.22 Soil Pore Water Characteristics Site 3................................. 70

Table 7.23 Oil Content of Soil Pore Water......... 78

Table 7.24 Oil Content Data for Deep Cores........ 80

Table 7.25 Priority Polluants Present in Unsaturated Zone Cores.................. 81

Table 8.1 Concentrations of Hydrocarbons Emitted at Sites 1 and 3............... 85

Table 9.1 COD/TOC Concentrations of Runoff....... 88

Table 9.2 Oil and Grease Concentrations of Runoff............................. 88

Table 9.3 Metal Concentrations in Runoff Water... 89

Table 10.1 Oil Content Analysis..................103

Table 10.2 Mean Values for Tree Height and Width..104

Table 10.3 % Oil Content 8 Centimeters from Tree Base............................108

Table 10.4 Nutrient Analysis for Field Sites......111

Table 10.5 Oil Content of Grass Plots............112

TABLES (continued)

Table 10.6 Environmental Chamber Soil Characteristics........................113

Table 10.7 Mean Height Values for Grass...........114

Table 10.8 Above Ground Biomass of Grass..........115

ABBREVIATIONS AND SYMBOLS

TOC	Total Organic Carbon
COD	Chemical Oxygen Demand
CEC	Cation Exchange Capacity
GC	Gas Chromotography
GC/MS	Gas Chromatography/Mass Spectrometry
PNA	Polynuclear Aromatic
mg/l	milligrams per liter
ppb	parts per billion
ppm	parts per million
mg/kg	milligrams per kilogram
Ag	silver
Ac	aluminum
As	arsenic
Ba	barium
Cd	cadmium
Co	cobalt
Cr	chromium
Cu	copper
Fe	iron
Mn	manganese
Ni	nickel
Pb	lead
Se	selenium
Zn	zinc

ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance of Dr. Eric Enwall and Dr. Tom Karns of the Chemistry Department at the University of Oklahoma for their great assistance in the identification of organic compounds by GC/MS. We would also like to thank project officer Dr. Don Kampbell and Mr. Leon Meyers of the Robert S. Kerr Environmental Research Laboratory, for their assistance and guidance during this project. We would also like to acknowledge the advice and assistance of Dr. R.L. Dalrymple of the Noble Foundation of Oklahoma, and Drs. John Fletcher, Elroy Rice and George Goodman for their advice on the revegetation study. We would also like to express our appreciation to Cindy James, Nancy Laudick, Charles Carpenter and Vickie McFarland for their assistance with the analytical work. Finally, we would like to express our sincere appreciation to Barbara Jones and Betty Craig for the preparation of the manuscript.

SECTION 1

INTRODUCTION

Land treatment as a method of disposal of oily residues from oil refinery operations has become very popular in recent years. The technique has been in use for 15 to 20 years, and several studies have been performed to determine the fate of the oil and metals at active land treatment sites. However few studies have been carried out on the long-term effects on the site soil of land farming operations, or on monitoring the unsaturated zone at closed sites to see if a long-term threat to ground water exists at these sites. The purpose of this report is to describe a study carried out at three closed (inactive) land treatment sites. The major objectives of this study were:

1. To identify priority pollutants present in the site soil at depths up to 152 cm (60 inches).
2. To identify priority pollutants present in soil-pore water at a depth of 1.2 m (4 feet).
3. To identify grasses and/or trees which would grow at land treatment sites used for oily residues.
4. To determine the environmental impacts resulting from land treatment of residues from an oil refinery with emphasis on closure of land treatment sites.

Specifically the environmental objectives included identification of the quality of runoff and volatile emissions from the sites, vertical migration of pollutants, and evaluation of changes in soil characteristics as a result of land treatment activities.

To achieve these objectives land treatment sites which had been in use for a number of years were selected. Soil samples from depths 0-25 and 25-51 cm were analyzed for oil content, metals, TOC, COD, pH, nutrients, chloride, cation exchange capacity, and selected organic priority pollutants. The unsaturated zones at the sites at depths from 51-152 cm were sampled, and the samples analyzed for oil content, metals and selected organic compounds. The soil-pore water in the unsaturated zone was sampled using vacuum soil-pore water samplers (lysimeters), and the samples analyzed for oil content, metals, TOC, COD and selected organics.

The 0-25 and 25-51 cm depths were chosen, because land treatment sites are tilled, and the till zone usually extends to a depth of about 25 cm. Since this depth is completely mixed during tilling, it was felt that sampling shallower depths would be unproductive. The depth 25-51 cm was chosen since preliminary sampling at these sites indicated the presence of oil in some areas of the sites down to this depth.

Samples of soil-pore water were collected as a part of the unsaturated zone monitoring program, to see whether any pollutants were passing through the unsaturated zone, and if so, in what quantities.

Samples of the 0-25 cm and 25-51 cm zones were analyzed for oil content over the duration of the project, in an attempt to determine rates of degradation. In addition a part of each site was tilled periodically, to see if this enhanced the rate of degradation when compared to the untilled section of the site.

The major thrust in the analysis of the site soil and soil-pore water for priority pollutants, was to identify qualitatively the compounds present. Quantitative evaluation was beyond the scope of this project, although concentrations of the compounds identified were calculated, to give an idea of the concentrations of the compounds identified.

Parameters measured other than priority pollutants are all important in determining the rate of removal of oil through degradation, emission etc., and the potential for mobilization of pollutants.

The site soil was also evaluated for changes in permeability, soil structure, soil texture and cation exchange capacity.

SECTION 2

CONCLUSIONS

This study suggests a number of factors which should be considered in any closure monitoring program.

(1) The soil pore water passing through the unsaturated zone may contain high levels of salts, especially chloride, as well as high levels of iron and manganese and other oxidizable material. Our results show that chloride levels decrease with time, but persist for longer than the 90 days now required for monitoring soil pore water after waste application has ceased. This information indicates that monitoring of the soil pore water for longer than 90 days is required.

(2) Some vertical migration of oil did occur at the study sites, but this migration did not extend below 50 centimeters of the surface. No oil was present in the soil between 50 and 150 cm, at these sites.

(3) Metals in land treatment site soils were immobilized in the top 25 cm of the soil. Some soil pore water samples from the sites contained concentrations of Ba which exceeded the primary drinking water standards levels and Fe and Mn which exceeded secondary standards.

(4) Organic priority pollutants in our land treatment site soils were primarily polynuclear aro-

matic compounds and phenols. Several of them were found in the unsaturated zone in the ppb range. Apparently movement of pollutants into the unsaturated zone occurred.

(5) Sampling procedures at land treatment sites must be carefully designed, since there is considerable variability in oil concentrations across a site.

(6) Reduction of oil content levels to background may not be possible at land treatment sites. One site in our study was well managed, had nutrient levels which supported profuse vegetative growth and had no residues applied for 6 years. The soil at this site still had an average oil content level of between 2½ and 3 percent. Thus, it may be more practical to reduce levels to the point where leaching, hydrocarbon, emissions, plant inhibition and pollutant surface runoff are no longer problems.

(7) Vegetative cover reduces contamination of runoff with site pollutants, and improves appearance.

(8) Increased amounts of volatile hydrocarbons will be emitted during the tilling process for an extended period of time after waste application has ceased.

(9) Revegetation of land treatment sites with high oil concentrations is not desirable since root development is inhibited. Grasses are the best for initial revegetation. They provide a quick cover, aerate the soil, have root systems which can hold the top layer of soil in place.

(10) A ground cover using certain grasses can be established at oil concentrations of 4 to 5

percent. However, root development and crop yield is significantly inhibited.

(11) At the time of closure the land treatment site should be tilled at frequent intervals and nutrients applied until the oil concentration has decreased to a maximum of 3 percent prior to attempting to establish a ground cover using forage crops (grasses).

SECTION 3

RECOMMENDATIONS

This study indicates the need for further research in the following areas.

(1) Identification of organic compounds present at land treatment sites both qualitatively and quantitatively. A major consideration needs to be studies on the recovery of organics from soil matrices.

(2) Work is needed on soil pore water monitoring at sites. Different methods of installation for the pore water sampler need to be evaluated. The effect of the porous ceramic cup on pollutants in the soil pore water, especially organic priority pollutants, needs evaluation.

(3) Hydrocarbon quantities emitted at land treatment sites need to be evaluated. Air emissions could be an important mode by which hydrocarbons are lost from sites.

(4) Research is needed on revegetation of sites used for land treatment of oily residues. Areas of investigation should include:

   (a) the identification of waste tolerant species including legumes.

   (b) the determination of waste constituents bio accumulated by plants.

   (c) the determination of good soil conditioning methods and planting techniques for revegetation.

(d) The selection of proper tilling practices.

SECTION 4

LITERATURE REVIEW

Prior to the development of this research project, a comprehensive literature review was carried out on the subject of land treatment of oily residues. This review encompassed management practices and monitoring techniques used at land treatment facilities, as well as any other relevant information.

Several researchers have investigated land treatment of oily residues in the last few years. These include Meyers and Huddleston, 1979; Huddleston, 1979; Huddleston and Meyers, 1978; Cresswell, 1977; Kincannon, 1972; and Raymond, Hudson and Jamison, 1976. The results of these research projects have been cited extensively in the literature and will not be reviewed in detail here. The general conclusion drawn from this work has been that land treatment is an environmentally sound and effective way to dispose of oily residues.

The factors affecting degradation of oily residues have also been investigated. Cresswell (1977) identified the primary factors affecting oil degradation rates in the soil as

1. petroleum composition
2. temperature
3. nutrients
4. oxygen availability
5. water
6. pH.

However, little data on the relative importance of these factors, and their interrelationships has been reported.

Most of the data produced by land treatment studies has focused on short-term effects. Few researchers have evaluated the potential for long-term impacts on the environment. These long term impacts need to be addressed in view of the fact that there is a buildup of heavy metals in the soil during land treatment. Fuller (1977) reported that under anaerobic conditions the mobility of several heavy metals (As, Cr, Fe, Cn, Zn) is enhanced. (Anaerobic conditions can and do occur at land treatment sites, particularly under conditions of high soil moisture content, when leaching is most likely to occur).

Hahne and Kroontje (1973) reported that in the presence of chloride ion, the solubility of Cd, Zn, Pb, and Hg is increased even at a pH as high as 9. They indicated that at a pH of 9 soluble chloride complexes can be found at ion concentrations of 354 to 28 ppm. High chloride ion concentrations can be present at land treatment sites because of the occurrence of brines with crude oil and the high chloride ion content of some of the wastes which result from refinery operations.

Huddleston et al. (1982) reported in a study carried out at five closed refinery land treatment sites, that wastes had been degraded without appreciable migration of degradation products and also, that metals in the waste remained in the waste application zone.

One problem which might arise from the disposal of oily residues by land treatment, is the movement of leachate through the unsaturated zone to the underlying ground water. This could result in contamination of the ground water. Thus, the unsaturated zone at a land treatment site needs to be monitored in order that any pollutant movement can be detected. Current EPA regulations require the use of monitoring wells, and the collection and analysis of soil core samples as a method of detecting pollutant movement. The EPA has also required the use of soil moisture samplers for sampling soil pore water in the unsaturated zone under active land treatment sites.

Soil moisture samplers using a porous ceramic cup have been used for many years for collecting soil pore water samples. Briggs and McCall first reported on the use of porous ceramic cups in 1904, and since that time, their usage has increased, especially in the last 10 to 15 years. However, with their increased usage questions have arisen as to the validity of samples collected in this way.

Wagner (1962) used the porous ceramic cup and reported no adsorptive capacity of the cup for nitrate ions, but an appreciable adsorptive capacity of about 1 mg of N for NH_4^+ ions. Reeve and Doering (1965) used ceramic cups to collect soil water samples for salinity determinations. The values obtained from the sampler agreed with the values obtained by the conventional saturation method. They also found that the composition of the sample changed with time, but that consistent and reliable values for the composition of the soil solution were obtained when a vacuum in the range of 0 to 500 millibars was used to collect the sample.

Grover and Lamborn (1970) reported that ceramic cups contributed excessive amounts of Ca^{++}, Na^+ and K^+ to solutions drawn through them, and adsorbed phosphorus from solutions containing phosphorus. They found that leaching the cups with 1 N HCl reduced Na and K contamination, and the amount of phosphorus adsorbed, but appreciable amounts of calcium contamination still occurred. Wood (1973) also reported contamination by Ca, Mg, Na, HCO_3^- and SiO_2 of the sample. He minimized the problem by leaching the ceramic cups with 8 N HCl.

Zimmermann, Price and Montgomery (1978) reported loss of nutrients after filtration through porous ceramic cups used to sample sediment. The most significant losses occurred with NH_3 and phosphate ions. Levin and Jackson (1977) also reported screening of NO_3-N when they used porous ceramic cups for sampling soil water. However, Johnson and Cartwright (1980) used soil moisture samplers with porous ceramic cups for sampling the unsaturated zone under landfills in Illinois. They found that samples taken with soil moisture samplers were representative of the surrounding leachate composition of major ions. They point out that while sample variability or bias of several milligrams per liter may be quite significant when the concentration of the ions of interest in the soil water is low, this is not the case when sampling highly contaminated leachate with high ionic concentrations.

Questions have been raised as to the validity of the samples collected using porous ceramic cups. England (1974) pointed out the following:

(1) Concentrations and composition of the soil solution are not homogeneous throughout its mass.

(2) Cations vary widely in the degree of dissociation from the surface of electro negative colloidal particles. Water drained from large pores at low suctions may have a different chemical composition from that extracted from micropores.

(3) Concentrations of various ions in a soil solution generally do not vary inversely with the soil water content. Dissolved quantities of some ions increase on dilution, while quantities of other ions may decrease.

Hansen and Harris (1975), did extensive work on the use of porous ceramic samplers. They found that the rate of sample uptake was strongly influenced by cup uptake rate, plugging of the cup, sampler depth, and the type of vacuum system used. They also found that a number of factors affected the sample concentration as the sample is drawn through the ceramic cup. These factors are intake rate, leaching, sorption and screening.

Van der Ploeg and Beese (1977) showed that the soil moisture sampler distorts the existing gradient patterns in the soil in such a way, that around the ceramic cup exaggerated percolation rates are created. They state that the composition of the collected sample is not representative for one particular depth, but reflects some average composition of the surroundings. Van der Ploeg and Beese found that extraction rates with even a small vacuum applied were much higher than the percolation rate under freely vertically draining conditions. They could find no relation between the amount of soil water extracted and the freely percolating soil water.

It thus appears that a great deal of care must be taken in extrapolating results obtained with the use of soil water samplers to conditions which actually exist in the unsaturated zone. This is especially true when dealing with environments where solute concentrations are low. Little has been written on the effect of the ceramic cups on low level organics which may be present in the soil water, and this is an area which needs more research.

The soil moisture sampler most commonly used in monitoring the unsaturated zone is a pressure vacuum model which was developed by Parizek and Lane (1970). This sample can be effectively used up to depths of 50 feet, and can be used to collect samples over a long period of time. This particular model has the advantage that it can be installed in a given location and the samples removed from the sampler at another location. For example, the sampler can be installed under an active landfill and the samples collected at the side of the landfill.

Soils used for the dosposal of oily sludges may contain a number of heavy metals which are potentially toxic to the environment. Contamination to ground water by heavy metals is believed to be of minimal concern if adequate soil pH is maintained at a land treatment site. Most metals are immobilized when soil pH is greater than 6.5. The leaching of metals, therefore is not of major concern on treatment sites with proper pH control (Dibble and Bartha 1979, Francsen 1980, Huddleston 1979).

Leeper (1978) believes that pH is the single most important aspect of the reaction between heavy metals and soils. Soil treated with sludges containing heavy metals should be medium to fine textured, have a pH above 6.5 and contain 3-7% organic matter with a C.E.C. of at least 14 in order to be considered acceptable for the retention of metals (Huddleston 1979, Leeper 1978, Loehr et al., 1979).

Hydrocarbon Processing (1980) reports that "virtually all published information on landfarming indicates that there is little migration of contaminants below the top 12 inches of soil". Little work has been done to date on the leaching of metals in soil containing oily waste, although the movement of heavy metals in landfills or in soils amended with sewage sludge has been studied extensively (Schilesky 1979).

Raymond et al. (1976) conducted a land treatment study in which oil degradation was monitored over a one year time period. The movement of lead, which was the metal of highest concentration in the oil, was examined and no evidence was found that the nitric acid-soluble form leaches through the soil.

Dibble and Bartha (1979) found hydrocarbons did not leach below a depth at which oil sludge was mixed with sandy soil. Based on Raymond et al.'s studies, Dibble and Bartha concluded that heavy metal residues from oil sludges would display low mobility in limed soil.

The possibility for the leaching of heavy metals through soil is great if high pH levels are not maintained at land treatment sites. Heavy metals can be toxic, therefore suitable oily wastes for land treatment are those which do not contain extremely high metal concentrations (Huddleston 1979).

Refinery waste streams contain a wide variety of pollutants. The EPA has reported a number of toxic pollutants which have been detected in treated effluents from refineries. A list of these pollutants is shown in Table 4.1. A review of the literature did not reveal any specific organic compounds which had been identified at land treatment sites for oily residues.

Interest in the effect of land treatment of oily residues on vegetation has increased as the usage of land treatment has increased. Observations of accidental oil spills, from pipelines or tankers, prompted investigations into the effects of crude oil on vegetation prior to the practice of land treatment. Much of this research, however, focuses on coastal tundra and marine species rather than on terrestrial plants.

There exists a lack of information concerning the affects of land-applied oily wastes upon vegetation. Studies have been conducted for crop species, but data on perennial plants are not readily available. The majority of information focuses on the germination, growth and yield of a variety of crop species.

Dibble and Bartha (1979) described a rehabilitation

TABLE 4.1. TOXIC POLLUTANTS DETECTED IN REFINERY TREATMENT EFFLUENTS

1. Organics

benzene
1,2-dichloroethane
1,1,2,2-tetrachloroethane
parachlorometacresol
1,2-trans-dichloroethylene
2,4-dimethylphenol
ethylbenzene
fluoranthene
methylene chloride
dichlorobromomethane
naphthalene
4-nitrophenol
phenol
bis(2-ethylhexyl)phthalate
diethylphthalate
benzo(a)anthracene
benzo(a)pyrene
chrysene
anthracene
benzo(g,h,i)perylene
fluorene
phenanthrene
pyrene
tetrachloroethylene
toluene
trichloroethylene

2. Pesticides

None

3. Metals

antimony (total)
arsenic (total)
chromium (total)
beryllium (total)
cadmium (total)
copper (total)
cyanide (total)
lead (total)
mercury (total)
nickel (total)
selenium (total)
silver
thallium (total)
zinc (total)

4. Others (Asbestos, 4AAP Phenol)

None

Ref: EPA "Development Document for Effluent Limitations Guidelines and Standards for the Petroleum Refining Point Source Category", EPA 440/1-79/014-b, December 1979, Effluent Guidelines Division, E.P.A.

program carried out for two years at the location of an underground pipeline break in a New Jersey winter wheat field. After emergency cleanup operations the 1.5 hectare wheat field which had been covered by 1.9 million liters of kerosine (no. 1 grade fuel oil) was rehabilitated by liming, fertilizing and frequent tilling.

In the spill area all of the wheat had been killed. Attempts were made to reestablish the plant cover ten months after the spill occurred. However, a good stand was not developed until two years after the spill.

Rehabilitation time was influenced by the type and quantity of oil, the nature of the contaminated soil and climatic conditions. Dibble and Bartha noted that decrease in oil concentration over time has a definite correlation with temperature. They concluded this decrease resulted from biodegradation and evaporation and was not due to leaching.

Dibble and Bartha (1979) performed a greenhouse study to see if a low concentration (0.34% wt/wt) of kerosine in the soil one year after contamination had an effect on the germination of wheat and soybeans. In the first ten days after planting, the seeds germinated at a slower rate compared to controls. After 24 days growth the wheat and soybean plants appeared stunted.

The authors concluded that since a nutrient solution was supplied to the plants, the slow rate of germination and stunting was due to competition for oxygen with hydrocarbonoclastic microorganisms.

Murphy (1929) also reported a delay in wheat germination when it was grown in soil containing small amounts of crude oil. Wheat seeds which failed to germinate had rotted kernels. Murphy found that mixing crude petroleum on the soil surface prevented seed germination, whereas germination was not affected when the petroleum was applied four inches below the surface.

Volatile-oil fractions have high "wetting" capacity and penetrating power. If they come into contact with plant seed, they enter the seed coat readily and kill the germ. Seed viability is less apt to decrease when the excess of oil volatiles has escaped from contaminated soil prior to planting (Plice 1948).

Knowlton and Rucker (1979) analyzed wheat grown on an oil refinery land treatment site. No heavy metals were found to have accumulated in the roots, stalks/leaves and grain of the plants.

Meyers and Huddleston (1979) also found no significant increase in the uptake of heavy metals by wheat grown on a land treatment site. Wheat germinated only on sites where there were low concentrations of refinery waste. Here, the plants developed more slowly than control plants and the grain had a 20% lower nitrogen content.

Meyers and Huddleston (1979) concluded that lower nitrogen content in the grain was the result of less nitrogen being available to the plants as a result of assimilation by microorganisms degrading the waste oil. Ross and Phung (1977) came to similar conclusions about nitrogen in their case studies with ragweed, ice plant, nutgrass and cocklebur. These investigators also found unusually high levels of Zn, Mo and Pb in nutgrass and cocklebur.

Giddens (1976) studied the effects of spent motor oil on peanuts, cotton, soybeans and corn. He postulated that lubricating oils containing predominately saturated hydrocarbons with 20-70 carbons created nutrient imbalances, especially of nitrogen when mixed with the soil

At oil rates of up to 31,111 liters/ha., Giddens was successful in growing peanuts, soybeans and corn when amply fertilized. Growth of sorghum and weeds was significantly reduced with high oil rates. The effect of numerous nitrogen additions to oil applied to a plant-soil system is not known (Overcash and Pal 1979).

Carr (1919) showed that soybean growth was somewhat improved by adding small amounts (up to 0.75%) of crude oil to soil and may even have been desirable in the development of nodules. A large amount (4%) of oil was able to be added before the soybeans succumbed to the treatment. The damage seemed to be due in part to the plants inability to secure water rapidly enough to meet its needs.

A survey of land in Great Britain which was naturally impregnated with hydrocarbons in the form of oil shales was done by Gudin and Syratt (1975). They found the most abundant plant species to be members of the Leguminosae. Oil polluted areas near the British Petroleum Company's Dunkirk refinery also showed a dominance of legume species. The abundance of legumes was thought to be due to symbiotic relationships with Rhizobium species. Because of the relationship with Rhizobium, legume species do not have to compete for nitrogen with microorganisms which break down hydrocarbons in soil.

McGill (1976) believes that it is probably advantageous to plant nitrogen fixing species on partially or completely reclaimed oil spill sites. This, however, is questionable because of the high nutrient requirements of some nitrogen fixers.

McGill reports that trees are not very tolerant of oil spill conditions and there is some evidence that the addition of fertilizer to oil contaminated soil is detrimental to some tree species. Grasses may be the most desirable type of plant to use for revegetation because of their root system.

The species of plant seeded on an oil contaminated soil should be adapted to the soil and climatic conditions in the area. Native species can be used but there is difficulty in obtaining viable seed or rootstocks. McGill feels that "tame" species are probably the best choice for revegetation when a quick cover is desired. He does caution that revegetation of a site containing large amounts of oil although possible, is not desirable until much of the oil has been degraded.

Plice (1948) studied over several years in Oklahoma, a variety of plant species and their relationship to soil fertility when various petroleum materials were applied to the soil. These plants included Darso sorghum, soybeans, field peas, wheat, barley, rye, hairy vetch, crimson clover and Hubam clover. Plice also observed the environmental effects of pipeline breaks.

Plice made some interesting observations. He noted that the amount of damage done and the time which was required for reclamation depended on the size of the area involved and the degree of saturation by the oil.

> Oil penetrations which do not go deeper into the soil than plow depth can usually be overcome within a year or two by cultivation - particularly if dry, sunny weather can lend a hand. The present study indicates that, in the case of deep penetrations of one foot or more, no attempt should be made to make cultivations until the oil has "weathered" to a depth somewhat greater than the soil will be plowed. Depending on the extent of subsequent hot and dry weather, this time period could be 2 or 3 years or even longer.
>
> Hot dry and sunny weather greatly hastens the escape of volatile fractions and, in time, removes the gumminess of the soil so that the soil will scour a plow (Plice 1948).

Plice noted that soils which were deeply oiled contained no vegetation for two full years. He cultivated such plots and noted that aggregates had been broken down even in clay soils. Cultivated soils were especially subject to blowing after periods of dry, windy weather. Uncultivated, heavily oiled soils were not subject to wind action.

In areas where oil spills have occurred, Plice has noted that deeply oiled soils react to moisture quite differently than do shallow oiled soils. Shallow oiled soils come to "moisture equilibrium" within a week or two after a good rain and will dry relatively fast in dry weather. Deeply oiled soils rather than being wetted directly by rainfall are wetted from the sides or moving ground water and thereby take longer to obtain moist surfaces. Once wet, however, deeply oiled soils, cultivated or not remained wet for many weeks. This knowledge is important to the growing of vegetation on oil spill sites.

Plice found that in the third summer of study crabgrass and blue grama grass was being established on the cultivated, deeply-oiled soils. In the fourth summer the plots were completely covered with a variety of natural grasses. After four years there was no growth of any sort on the uncultivated deeply-oiled plots.

Crop planting is recommended only after friability is restored to an oil inundated site. A decreased stand is almost inevitable at first. Plice (1948) and Carr (1919) both agree that the presence of oil in soil results in damage to plants because they are unable to obtain sufficient moisture and air.

In a recent study by Watts and Corey (1981) crabgrass was found to be the dominant species naturally encroaching upon their land treatment site in South Carolina. The extreme domination of crabgrass and total exclusion of dicots may prove to be interesting in the study of species tolerance to oil.

Inhibition of natural vegetation was apparent for two years in oil treated plots. After three years the species diversity of ruderal plants was very low. Small quantities of Cynadon dactylon, Dioda teres and Richardia scabra were observed. Crabgrass as mentioned previously dominated these sites.

Watts and Corey found that the germination of corn planted on their land treatment site one year after application had less than 10% germination on soil with an oil concentration of 21 l/m^2. The maximum height that the corn reached was approximately 40 cm before it died.

One of Watts and Corey's conclusions regarding vegetation on land treatment sites was that the primary inhibitory factor was the inverse relationship between oil content and soil water. In oil treated plots neither the CO_2 emanation rate nor the soil moisture increased with the addition of water. Water either pooled on the top of the soil or penetrated with no apparent wetting.

In addition, Watts and Corey showed that land disposal of waste oil increased organic matter, phosphorous, potassium and calcium content of the soil and decreased magnesium content for up to eight months after application. Along with these changes was an increased CO_2 evolution rate due to probable increases in microbial populations.

Brown et al., (1979) studied the impact of API separator sludges on the emergence and yield of ryegrass. They found depressed results with concentrations of hydrocarbons as low as 2% V/V in soil. Poor growth and yield were attributed to phytotoxic waste constituents and impaired water, air and nutrient relations.

Gudin and Syratt (1975) observed a competition for nitrogen between ryegrass and microorganisms degrading hydrocarbons in their greenhouse study even in the presence of additional nitrogen. A solid hydrocarbon residue had been incorporated into the soil at a rate of 500 kg/ha and the 50% disappearance time measured with and without a cover crop. The residue took 125 days to disappear without a cover crop as compared to only 50 days with a cover.

Data presented by Schwedinger (1968) clearly showed that, although set back, ryegrass can tolerate up to 3% of oil by weight of soil without showing severe signs of damage. Schwedinger also observed oats, sorghum, tomato, kale and lettuce plants in growth chamber studies. He noted the amount of crude oil plants can tolerate in soil is species dependent. Shallow rooted hardy grasses are probably least susceptible to the treated soil. Furthermore, the depth at which oil contamination occurred seemed to have no effect on the amount of damage plants suffered.

Plants grown on oil contaminated soil have a slow rate of water uptake and exhibit signs of nutrient deficiency, i.e. slowing of growth and yellowing of the bottom-most leaves. Schwedinger believes these symptoms of nutrient deficiency are related to the amount of water uptake. Damage is probably due to derangement of the relationship between the roots and the water in the soil.

In Coastal Arctic tundra studies by Linkins et al., (1976), oil was found to cause significant decreases in root respiration and changes in oxidative metabolism of roots. These changes occurred regardless of whether root-oil contact was early or late after oil application. Oil was found to cause greater perturbation of root respiration at lower temperatures.

Baker (1970) discovered that the leaves of young beans and peas, which were grown in oil-treated sand, showed a higher oil content than plants which were grown in normal soil. Oil absorbed by plant roots can move upwards in the plant. The mode of action, however, is undetermined.

Baker notes that most workers believe oil travels primarily in the intercellular spaces with little movement through the vascular system. Generally, the smaller the hydrocarbon molecule the more toxic the oil is to plants. Light oils have been shown to inhibit germination more than heavy oils at high concentrations because they penetrate the seed coat (Baker 1970).

Moisture is important for seed germination and plant growth. Hunt et al. (1975) noted that in areas where refined fuel oil was spilled on permafrost terrain there was extensive vegetative kill. Herbaceous plants are usually first to revegetate such spill sites where rainfall has leached fuel from the upper soil layers.

Data in this review of the literature on oil and the plant-soil system indicates that it may be possible to identify and develop plants which are oil tolerant. These plants would most likely be hardy species, able to survive the adverse environment brought about by an oil spill. Research and experimentation to develop plants which could be used to revegetate land treatment sites will require much trial and error. Soil characteristics of a land treatment site and composition of the waste residues applied to the soil will influence the success of any revegetation operation.

SECTION 5

SITE SELECTION

At the start of this project, the intention was to select four sites across the country which had been used for the land treatment of oily residues from petroleum refining. The idea was to select sites in varying climates, so that closed sites under differing conditions could be evaluated. However, sites outside of Oklahoma could not be obtained.

In selecting sites for use in this study, several factors in addition to climate were considered. These factors were

(1) The availability of data on what had been applied to the site.
(2) The time period for which the site had been used.
(3) The time period for which the site had been inactive.
(4) The management practices at the site.

Several refineries in Oklahoma which operated land treatment sites were visited, and based on these visits and discussions with plant personnel, three sites which best met the criterion were selected for use in the project. In addition, these sites reflected a range of oil loading, from low (<6%) to high (≡14%). These values are based on the oil content of site soil at the start of this project. The sites spanned the range of oil loading rates which are encountered at operational facilities.

In all three cases, a section of what had previously been active land treatment sites was selected for use.

In evaluating the sites one significant problem was encountered. Although land treatment of oily residues has been used for many years at oil refineries, records of operational procedures have only been maintained at most refineries since the late 1970's. As a result of this, limited recorded application and management data was available for the sites evaluated. Conversations with personnel responsible for management of these facilities revealed that the sites were all tilled regularly during operation, and nutrients were added to enhance degradation. The pH of the site soil at all three sites was in the range 6-8 (Table 7.12). A synopsis of the data available for the three sites selected is presented below.

Site 1

This site had been used for land treatment since July 1976. It was used in 1976, 1977 and 1979, but no analytical work was performed. The plot was not used in 1978. Starting in February 1980, records were kept of the type and quantity of waste being applied to the site. A tank farm was originally located at this site, but no data is available on spills etc., which might have occurred during the time the tank farm was located here.

The last application of residues to the section of the site investigated was on January 5, 1981. Available data shows that in 1980, approximately 170 cubic meters (1091 barrels) of oil were applied, with an oil content ranging from 3.3 to 79.2 percent. In 1981, 7 cubic meters (42 barrels) were applied with an approximate oil content of 2%. No vegetation was present on the site at the start of the project. However, a small amount of growth was observed on the untilled portion of the research plot during the monitoring activities at the site. The research was carried out on an area of approximately 0.3 hectares (.75 acres).

Site 2

This site has been used as a land treatment site since March 1974. It was used until the middle of 1976, with oil sludge and biosludge being applied in amounts of 157 to 236 cubic meters (400 to 600 barrels) of oil/hectare (2.47 acres). Precise analytical data is not available, but laboratory records indicate a 38% oil content for the oily sludge, and a 12% oil content for the biosludge. This site supported a luxuriant growth of vegetation over the entire area when the project was started, and continued to support vegetation during the project. Burrowing animals were also observed on the site during the project. This site was tilled and fertilized on a regular basis during its active life, and was a well managed site according to current regulations. The research was carried out on an area approximately 0.2 hectares (0.5 acres) in size.

Site 3

Site 3 has been in operation as a land treatment site since 1975. Prior to this, the oily residues were dumped in large pits which had a total capacity of 72,620 cubic meters (456,814 barrels). These pits were emptied in 1975, and their contents applied to the land treatment site. The area of the site is 2.85 hectares (7.04 acres), and personnel at the refinery estimated a water content of 60% for the contents of the pits. This means that approximately 10,196 cubic meters (25,955 barrels) of oily residue per hectare were applied to the site at the start of the land treatment operation in 1975. Records available for the period 11/25/80 to 1/9/81 indicate a total of approximately 970 cubic meters (6,100 barrels) of oily residues were applied to the site over a six week period. The research was carried out on an area of approximately 0.12 hectares (0.3 acres).

No information was available, from any of the refineries, on the exact source and/or nature of most of the residues which had been applied to the sites. In the few cases where the source of the applied residues was recorded, the location on the site where the residues had been placed was not noted.

At site 2 the residues were applied to alternate strips of land 61 meters long by 4 meters wide (200' x 13'), while at site 1 and 2 the residues were applied to the whole site.

SITE SOIL CHARACTERISTICS

The soil at the sites was characterized with respect to the following parameters:

(a) texture
(b) permeability
(c) X-ray diffraction
(d) cation exchange capacity.

Composite samples were collected from each site, as well as from areas adjacent to the sites. The samples from adjacent areas were analyzed to provide background data by which to evaluate any changes which had taken place.

Gradation Analysis

Grain size distributions for the soils were determined in accordance with ASTM Designation D422-63(72) (AASHTO Designation T-88-78). The deflocculating agent used was calgon solution. Further dispersion of clay particles was accomplished by applying a 10 psi air pressure from the Iowa dispersion jet for 5 minutes. Grain size distribution tests were run on the fraction of soil passing sieve #10 (2mm). For soils with oil contamination it was not possible to run the hydrometer test, because it was not possible to read the hydrometer correctly while oil was covering it. Interference from the oil occurred even after the samples had been subjected to extraction with freon and dichloromethane for 24 hours.

Analyses were performed on soil samples taken from areas adjacent to the sites, and these resulted in the following classifications.

TABLE 5.1. SITE SOIL TEXTURAL CLASSIFICATION

Site	Classification
Site 1	Silty loam
Site 2	Sandy loam
Site 3	Clay

Permeability

Permeability tests were conducted on samples of background soil, as well as composite samples of the top 25 cm of site soil at each of the three sites. Soil samples from the sites were collected and standard laboratory permeability tests were run, using a modification of the constant head permeability test (AASHTO Designation: T 215-70, ASTM Designation: D 2434-68 (1974)). The constant head method is preferred over the falling head method for such fine-grained soils because of the relatively low permeability coefficients obtained.

The procedure was modified somewhat from the standard method in that a nitrogen cylinder was used to create the pressure head instead of the constant head filter tank. In this way it was possible to control the amount of pressure used to make the water permeate the soil matrix and maintain laminar flow. Before testing began the optimum moisture content for each sample was determined from a standard proctor test (AASHTO Designation: T-99). Water was then added to each sample to bring it up to optimum moisture. The soils were compacted into the permeameter mould, and tap water was added on top. The soils were left to saturate for 48 hours. At the end of the 48 hours the pressure was turned on. The volume of water collected per time was recorded and the coefficient of permeability was calculated. The samples on which these permeabilities were determined were composite samples taken from the top 25 cm of soil. The results are shown in Table 5.2.

No significant differences between the permeability of the background and site soil was observed at sites 1 and 3.

TABLE 5.2. SOIL PERMEABILITY VALUES

Site/Location	Permeability (water) (cm/sec)
Site 1 - Background	9.6×10^{-8}
Site 1 - Site Soil	5.03×10^{-8}
Site 2 - Background	-
Site 2 - Site Soil	1.3×10^{-6}
Site 3 - Background	1.95×10^{-7}
Site 3 - Site Soil	0.91×10^{-7}

X-Ray Diffraction

Composite samples of site soil and background soil were subjected to x-ray diffraction analyses. These analyses were performed using a Phillips Electronics APD 3600 Automated Power diffractometer. A comparison of the site soil patterns with those of background, revealed that some changes had taken place in the site soil structure.

Site 2

Soil samples from the site and one background sample were analyzed. The crystallinity of the soil samples did not change significantly in the site samples when compared to background. The decrease in intensity of the montmorillonite and chlorite peaks was more pronounced as the oil content increased. A possible explanation for this is that oil penetration into the interplanar layers of the minerals masked the effect of the crystalline materials. The calcite peak increased in intensity.

Site 1

The same trend as was observed at site 2 is observed here. Again the calcite peak increased in intensity.

Site 3

The general trend of decreased peak intensities with increased oil content is again evident here, with the exception once again of the calcite peak, which increased in intensity in one sample and decreased in intensity in the other.

Generally, the major peaks either remained the same or diminished in intensity with increasing oil content. The exception to this trend was the calcite peak, which generally increased in intensity with increasing oil content. The X-ray diffraction spectra are shown in Appendix D.

Cation Exchange Capacity

The cation exchange capacity of the site soil and background was determined using the ammonium saturation method. The CEC of the top 25 cm - zone of incorporation - was determined. The results reveal that at sites 1 and

2, there was generally an increase in CEC where oil was applied to the soil. However, at site 3, the CEC of site soil was slightly lower than that of the background soil. The CEC values of the site soil are listed in Table 5.3.

TABLE 5.3. CATION EXCHANGE CAPACITY OF SITE SOIL

Location	CEC (m.equivs./100g)
Site 1	
Area 1	15.4
Area 3	16.4
Area 6	19.5
Background	15.0
Site 2	
Area 6 - Untilled	14.6
Area 6 - Tilled	14.5
Area 3	7.0
Background	7.1
Site 3	
Area 2	12.1
Area 3	14.1
Area 4	13.6
Background	14.9

SECTION 6

EXPERIMENTAL APPROACH

Land treatment sites which had been in use for a number of years were selected. Soil samples from depths 0-25 cm and 25-51 cm were analyzed for oil content, metals, TOC, COD, pH, nutrients, chlorides, cation exchange capacity, and selected organic compounds. The unsaturated zones at the sites 51-152 cm were also sampled, and analyzed for oil content, metals and selected organic compounds. The soil pore water in the unsaturated zone at a depth of 4 feet was also sampled using soil pore water samplers, and the samples analyzed for oil content, metals, TOC, COD and selected organics.

The 0-25 cm and 25-51 cm depths were chosen, because land treatment sites are tilled, and the till zone usually extends to a depth of about 25 cm. Since this depth is completely mixed during tilling, it was felt that sampling shallower depths would be unproductive. The depth 25-51 cm was chosen since preliminary sampling at these sites indicated the presence of oil in some areas up to this depth.

Samples from the deeper unsaturated zone were analyzed to see if any migration of pollutants had occurred.

Samples of soil pore water were collected as a part of the unsaturated zone monitoring program, to see whether any pollutants were passing through the unsaturated zone, and if so in what quantities.

Samples of the 0-25 cm and 25-51 cm zones were analyzed for oil content over the duration of the project, in an attempt to determine rates of degradation. In addition a part of each site was tilled, to see if this enhanced the rate of degradation when compared to the untilled section of the site.

The major thrust in the analysis of the site soil and soil pore water for organics, was to identify qualitatively the compounds present. Quantitative evaluation was beyond the scope of this project, although concentrations of the compounds identified were calculated, to give an idea of the order of magnitude of the concentrations of these compounds.

The other parameters measured are all important as indicators of the amount of oil present, and the potential for mobilization of pollutants, especially metals.

The main objective of the revegetation study was to identify trees or grasses which would grow in oily soil and possibly aid in the recovery of land treatment sites.

SAMPLING PROCEDURES

Each site was divided into six sections, after initial sampling and oil content analysis at sites 1 and 2. These initial samples were collected randomly. However, an examination of the results of this initial round of sampling revealed that there was considerable variability in oil content across the site. Thus, to obtain more representative samples, it was decided to subdivide the sites, and then sample randomly within each area, compositing the samples. Five cores were composited from each section, giving a total of 30 samples (6 composites) per site. This number of samples was enough to yield an error in the estimate of the means of a maximum of 1%, and usually less than 0.5% for the oil content of the site soil.

A visual inspection of the cores taken, coupled with the results of the initial oil content determinations, led to the decision to sample the top 25 cm and the 25 centimeters directly below it, to ascertain the extent to which the oil had migrated. The samples were collected using soil sampling tubes. Initially Hankinson soil sampling tubes were used, but these proved too fragile for the types of soil being sampled, and stronger samplers were fabricated in the School of Civil Engineering and Environmental Science. The soil samples were all collected using these samplers, unless otherwise indicated. This sampling procedure was used for samples from the 0-25 cm and 25-50 cm depths.

Deep Core Sampling

The deep core samples were obtained by drilling a hole below the zone of incorporation using an auger, cleaning out the hole, and then using a soil core sampler to collect samples from the desired depth. In this way, samples up to a depth of 152 centimeters (60 inches) were collected at each site. Deep core samples were collected at each site each of the two years of the project. These deep core samples were not composited.

Soil Pore Water Sampling

The soil water passing through the unsaturated zone beneath the zone of incorporation was also sampled. Sampling of the soil pore water was accomplished by installing soil moisture samplers (lysimeters) at a depth of approximately 1.2 meters (4 feet) at the sites. The sampler used was Model 1920, sold by Soil Moisture Incorporated of California. Before the samplers were installed, an evaluation was made of the methods suggested by the vendor for installation of the samplers, and the following method of installation was adopted as a result of this evaluation.

A 10 cm (4 inch) hole was drilled to the required depth, and thoroughly cleaned out, making sure that none of the oil contaminated soil from the zone of incorporation was in the hole. The bottom of the hole was tamped, and then the sampler was seated in very fine-300 mesh-silica sand, so that the ceramic cup of the sampler was completely covered. Parent soil (15 cm) was then put into the hole, and tightly tamped. A layer of dry bentonite clay was then put into the hole followed by more parent soil. The hole was filled to about 20 centimeters (8 inches) from the top with parent soil, which was added in small amounts and tightly tamped. Another layer of dry bentonite clay was then added (5-8 cm) and the hole filled with soil. Figure 6.1 is a diagram of the mode of installation.

The sampling locations for soil pore water and deep core samples were installed at randomly selected locations in 3 or 4 areas at each site. The areas at each site were chosen to span the range at each site were chosen to span the range at oil concentrations measured at the site.

The samples collected were all identified by a code which identified the site from which the sample was taken, the date of collection and the type of sample. The sample could also be identified as being from a tilled or untilled area, in the case of site 2.

The site code consisted of a seven digit number with 1 or 2 letters after it, e.g. 1111282S or 1111281SW. The first digit identified the site, the next six the date, and the last two letters identified the sample type. The code 1111281S would refer to a soil sample from site 1 collected 11/12/81. The areas within the site were identified using the numbers 1 to 6, and the letter T or B to represent the depth 0-25 cm and 25-51 cm respectively. An additional T or U was used to differentiate

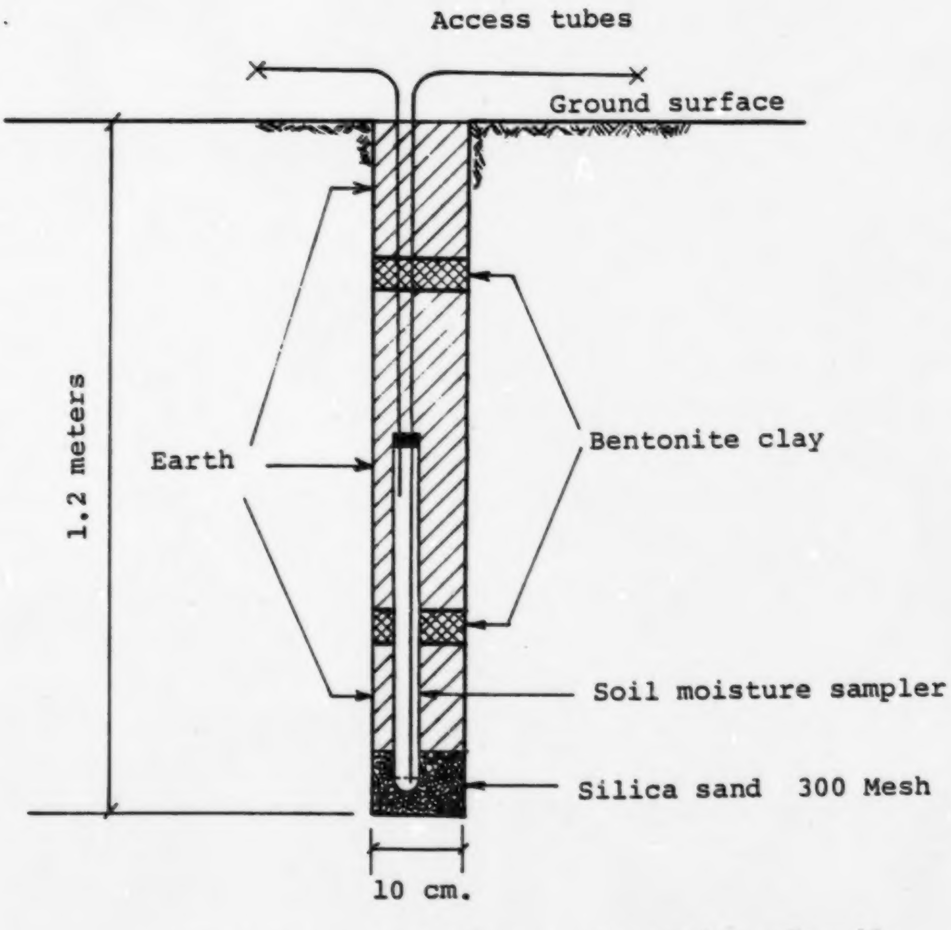

Access tubes
Ground surface
1.2 meters
Earth
Bentonite clay
Soil moisture sampler
Silica sand 300 Mesh
10 cm.

Figure 6.1. Method of installation of soil pore water samples.

tilled areas from untilled areas at site 2. Thus:

1T - Top (0-25 cm) sample from area 1
3TT - Top sample from the tilled section of area 3
2TU - Top sample from the untilled section of area 2
S - Soil sample
SW - Soil water sample.

The soil samples which were taken for purposes of comparison with the soil pore water samples, were taken at a distance of 6 feet from the soil moisture sampler.

SECTION 7

EVALUATION OF SITE CHARACTERISTICS

ORGANICS

The site soil was tested for the presence of selected priority pollutants. The samples were first extracted with methylene chloride using the Soxhlet extraction procedure, and then that extract was subjected to separatory funnel liquid - liquid extraction. These procedures are Methods 3540 and 3510 in "Test Methods for Evaluating Solid Waste" (2nd edition).

Three different sets of samples from each site were analyzed during the project, to identify any persistent organics present as definitely as possible. Table 7.1 lists the organic compounds evaluated, and Table 7.2 the compounds identified as present at the sites. This identification is essentially qualitative, since no studies on the recovery of organics from soil matrices were carried out during this project. However, Tables C-1 to C-4 in Appendix C contain the concentrations of the compounds identified at the sites. These values are intended as a guide to the order of magnitude of the concentrations of the compounds identified at the sites.

At site 1, many of the 19 compounds identified were at very low concentrations in the <.001 ppm range. However, some compounds (polynuclear aromatics) turned up at quite high concentrations. These compounds were also the ones present in the highest concentrations at site 3. Phenol showed a definite trend at site 1, increasing in

TABLE 7.1 PRIORITY POLLUTANTS

Base/Neutrals

1,3-Dichlorobenzene
1,4-Dichlorobenzene
Hexachloroethane
1,2-Dichlorobenzene
Hexachlorobutadiene
Naphthalene
Bis(2-chloroethyl) ether
Nitrobenzene
Bis(2-chloroethoxy) methane
Hexachlorocyclopentadiene
2-Chloronaphthalene
Acenaphthylene
Acenaphthene
Isophorone
Fluorene
2,6-Dinitrotoluene
1,2-Diphenylhydrazine
2,4-Dinitrotoluene
Hexachlorobenzene
4-Bromophenyl phenyl ether
Phenanthrene
Anthracene
Dimethylphthalate
Diethylphthalate
Fluoranthene
Pyrene
Di-N-butylphthalate
Butylbenzylphthalate
Benzidene
Chrysene
Bis(2-ethylhexyl)phthalate
Benzo(a)anthracene
Benzo(b)anthracene
Benzo(a)pyrene
Dibenzo(a,h)anthracene
Indeno(1,2,3-c,d)pyrene
Benzo(g,h,i)perylene
*Lindane
*Methoxychlor
*Endrin
*2,4-D
*2,4,5-TP Silvex
Benzo(k)fluoranthene

Phenolics

2-Chlorophenol
Phenol
2,4-Dichlorophenol
2-Nitrophenol
p-chloro-m-cresol
2,4,6-Trichlorophenol
2,4-Dimethylphenol
2,4-Dinitrophenol
4,6-Dinitro-o-cresol
4-Nitrophenol
Pentachlorophenol

Volatiles

1,4-Dichlorobutane
2-Bromo-1-chloropropane
1,1-Dichloroethane
Trans-1,2-dichloroethene
Chloroform
1,2-Dichloroethane
1,1,1-Trichloroethane
Carbon tetrachloride
Bromodichloromethane
1,2-Dichloropropane
Trichloroethene
Dibromochloromethane
1,1,2-Trichloroethane
Benzene
Bromoform
1,1,2,2-Tetrachloroethene
1,1,2,2-Tetrachloroethane
Toluene
Chlorobenzene
Ethylbenzene

TABLE 7.2 ORGANIC COMPOUNDS IDENTIFIED IN SOIL AT LAND TREATMENT SITES

	Site 1	Site 2	Site 3
Anthracene	x	x	
Phenanthrene	x	x	
Fluoranthene	x		x
Pyrene	x	x	x
Naphthalene	x	x	
Chrysene	x		
Benzo(b)fluoranthene	x		
Benzo(a)anthracene	x		x
Benzo(a)pyrene	x		x
Dibenzo (a,h)anthracene	x		x
Benzo(g,h,i)perylene	x		
Isophorone	x	x	x
Bis(2-ethylhexyl)phthalate	x	x	x
Butylbenzylphthalate	x	x	
1,2-diphenylhydrazine		x	
Phenol	x	x	x
Pentachlorophenol	x	x	
4-Nitrophenol		x	
2-Nitrophenol		x	
2,6-dinitrotoluene			x
Benzene	x	x	x
Toluene	x		x
Ethylbenzene	x		x
Bromoform			x

x Denotes compound which was present.

concentration over the sampling period 11/10/81 to 12/1/82. Thirteen of the 19 compounds were polynuclear aromatics (PNA's).

At site 2, 13 compounds were identified at the site, 6 were PNA's and 4 were phenolics. The compounds present at highest concentrations were again polynuclear aromatics. Trace amounts of phthalates were found, but no volatiles.

Thirteen compounds were identified at site 3, with 6 of them being PNA's. Four volatiles were also identified at this site.

Only pyrene, isophorone, bis(2-ethylhexyl)phthalate, phenol and benzene were identified at all three sites. Volatile compounds were identified mainly at sites 1 and 3, which had residues applied more recently than site 2.

Table C-1 in Appendix C lists compounds which were found in the background samples taken at the three sites. The concentrations of the compounds identified was quite low, but so were most of the concentrations at the sites. The reason for the presence of these compounds in the background samples is not clear. All of the sites were located at refineries, and the background samples were taken near the land treatment area itself. It may be that the background samples were taken too near to the treatment area, and the soil was slightly contaminated, or these compounds may be present naturally. Phthalates, for example, seem to be present everywhere, and bis-(2-ethylhexyl)phthalate was present in the background samples from all sites. Other compounds present in the background samples from all sites were chrysene and benzo(a)anthracene.

OIL CONTENT

Determinations were made of the oil content of the soil at each of the 3 sites during the course of the project. The objective of these tests was to determine:

(1) The variability in the oil concentration across the site.

(2) Whether oil was still present at the site.

(3) The extent to which the oil was degraded over the research period.

(4) The extent to which the oil had migrated vertically.

A part of each site was tilled during the project to see if tilling had any effect on the rate of degradation when compared to the untilled area.

Variability of Oil Concentration

As described in the section on sampling, the research area at each site was divided in 6 sections, and composite samples taken from each section. These composites were made up of 5 individual cores which were thoroughly mixed before analysis. It is apparent from the oil concentrations present in the different sections at each site, that there was great variation in the oil content across the site. However, there was even great variation within each section at the sites. Table 7.4 shows some oil content values obtained from individual cores taken at site 3. The cores were from three different areas at site 3. Table 7.5 shows the results obtained when individual cores were analyzed from one area and compared to a composite sample taken from the same area at site 2. It can be seen that at site 2, the oil concentration of the composite of 5 cores was very close to the mean of the concentrations of 5 individual cores taken from the same location.

Oil Content of Site Soil

The soil at each site was sampled periodically over the project period, and the samples analyzed for oil con-

TABLE 7.4 VARIABILITY OF OIL CONCENTRATION AT SITE 3

Area 1	Sample #	% Oil
	1	5.0
	2	8.7
	3	3.6
	4	4.1
	5	2.9
	6	7.7
	7	3.6
	8	3.8
	9	2.3
	10	5.3

Mean concentration = 4.7
Standard deviation = 2.07
Variance = 4.28

Area 2	Sample #	% Oil
	1	4.1
	2	5.0
	3	4.5
	4	6.2
	5	8.8

Mean concentration = 5.7
Standard deviation = 1.88
Variance = 3.55

(continued)

TABLE 7.4 (continued)

Area 3	Sample #	% Oil
	1	14.1
	2	8.3
	3	8.3
	4	4.7
	5	12.9
	6	7.2
	7	13.8
	8	5.7

Mean concentration = 9.4
Standard deviation = 3.71
Variance = 13.74

Table 7.5 Variability of Oil Concentration at Site 2

Area 6 Top	Sample #	% Oil
	1	1.5
	2	4.2
	3	6.3
	4	4.5
	5	6.5
	Composite	4.7

Mean concentration = 4.6
Standard deviation = 2.02
Variance = 4.07

Area 6 Bottom	Sample #	% Oil
	1	0.9
	2	3.8
	3	0.3
	4	0.4
	Composite	1.7

Mean concentration = 1.4
Standard deviation = 1.65
Variance = 2.74

tent. A part of each site was tilled, so that the rate of degradation in the tilled vs. the untilled sections could be evaluated. At site 1, half of the site was tilled, and the other half left untilled. At site 2, the land treatment site had had the residue applied to alternate strips of land. At this site, half of each strip was tilled, and the other half left untilled. At site 3, where the revegetation study was carried out, only a small portion of the site was tilled - Area 6.

Results

Table B-4 show the oil content concentration in the 0-25 cm (T) and 25-51 cm (B) layers of soil at the three sites. At site 1, areas 4, 5 and 6 were tilled. At site 3 only area 6 was tilled, while half of each area at site 2 was tilled.

Site 1

At site 1, there was a significant difference (95% level)between the site oil content and the background for both the top (0-25 cm) and bottom (25-51 cm) levels. However, there was no significant difference in the oil concentration of the top and bottom layer on April 4, 1982 and December 1, 1982, which means that little or no degradation had taken place over this period of time. The paired t-test at a 95% confidence level was used for the latter comparison. The mean oil content values are given in Table 7.6.

Site 2

At site 2, as mentioned before, the strips with the oil applied had one half of each strip tilled 4 times during the research project. The oil content of the site soil did not change significantly over time. These was no significant change between March 1982 and February 1983 in the concentration of oil in the top tilled sec-

TABLE 7.6 OIL CONTENT DATA - MEANS
SITE 1

Date		Mean %	Std. dev.	Variance
*Background Top		0.56	0.30	0.090
*Background Bottom		0.13	0.06	0.003
4/8/82				
	Top	4.90	1.52	2.30
	Bottom	0.64	0.35	0.12
12/1/82				
	Top	5.62	2.33	5.45
	Bottom	1.85	1.40	1.96

* Mean of all background concentrations.

TABLE 7.7 OIL CONTENT DATA - MEANS
SITE 2

Date		Mean %	Std. dev.	Variance
*Background Top		0.43	.152	.023
*Background Bottom		0.40	0.10	0.01
4/6/82				
	Top, tilled	2.63	0.96	0.92
	Bottom, tilled	0.78	0.37	.14
	Top, untilled	2.95	0.52	0.28
	Bottom, untilled	-	-	-
7/8/82				
	Top, tilled	2.58	0.95	0.902
	Bottom, tilled	1.08	.33	0.11
	Top, untilled	2.60	1.72	2.97
	Bottom, untilled	1.17	0.58	0.34
11/19/82				
	Top, tilled	2.93	1.46	2.14
	Bottom, tilled	1.46	1.31	1.72
	Top, untilled	2.65	1.67	2.79
	Bottom, untilled	1.08	1.14	1.29
2/16/83				
	Top, tilled	2.97	1.70	2.89

* Mean of all background concentrations

tion of the site. These was no significant change in oil concentrations in either the tilled or untilled, top or bottom areas over the period January to November 1982. There was also no significant difference between the oil content of the tilled and untilled sections of a given strip at the end of a 12 month period.

The site oil concentrations top (0-25 cm) and bottom (25-51 cm) were all significantly higher - 95% confidence level - than background, except for the bottom tilled sample of 4/6/82. The mean concentrations of oil at the site are given in Table 7.7. It should be noted that average oil content of the top samples at this site were quite low, ranging from 2.58% to 2.95%. The oil content of the background top sample of 8/5/82 was not included in the calculation at the mean background site concentration, but was treated as an outlier. This was done because the sample was apparently taken from an area which was contaminated with oil after we started working at the site.

Site 3

The same trend as at the other two sites was noted here. There was no significant change in average oil content of the site between March 1982 and June 1983. However, there was a significant difference between the oil concentration of the site soil and the background concentrations. A 95% confidence level was used for the statistical analysis of the data. The mean site oil concentration values are given in Table 7.8.

Discussion of Results

There was not significant degradation of the oil present at the sites during the research period. A number of factors could account for this lack of degradation. These include:

TABLE 7.8 OIL CONTENT DATA - MEANS
SITE 3

Date		Mean %	Std. dev.	Variance
*Background Top		0.57	0.50	0.25
*Background Bottom		0.10	0.0	0.00
3/26/82	Top	8.7	2.90	8.42
	Bottom	2.7	4.57	20.85
6/7/83	Top	9.03	4.85	23.56
	Bottom	5.13	4.62	21.42

* Mean of all background concentrations.

TABLE 7.9 COMPOSITION OF OIL AT SITES 2 AND 3

	Asphaltenes %	Saturates %	Polar Compds % %	Aromatics %
Site 2				
6T	18.0	28.0	32.0	22.0
6B	8.4	27.4	30.5	33.7
Site 3				
5T	12.4	32.4	37.6	17.6
4B	8.2	35.8	34.9	21.1

(1) The oil at the site contained appreciable amounts of polynuclear compounds, which are difficult to metabolize. Table 7.9 lists the fractions found in the residues from sites 2 and 3.

(2) There were long periods during which the site soil was quite wet, which could have inhibited the microorganisms by creating anaerobic conditions in the soil.

(3) The levels of nitrogen in the soil were too low and inhibited microbial metabolism of the oil. No nutrients were added to the sites during the research period, except for the revegetation study at site 3 and low levels of nitrogen were found in the soil at sites 1 and 3. However, it must be noted that at site 2, vegetation grew profusely, indicating that nutrient levels were high enough for degradation to take place, if readily degradeable material were present. Table 7.10 shows levels of nitrogen and phosphorus found at the sites.

Oil was present below what is commonly referred to as the till zone (0-25 cm) at all three sites. Oil was found as deep as 45-50 cms at all 3 sites. This suggests strongly that vertical migration of oil below the till zone occurs; occasional deep tilling or discing of the soil may be necessary to bring this oil up to the aerobic upper soil layers where it can be degraded.

The raw oil content data is given in Appendix B.

METALS

The concentration of selected heavy metals in site soil was determined, and compared to background metal concentration. A 95% confidence level was used in all

TABLE 7.10 NITROGEN AND PHOSPHORUS IN SOIL AT SITE*

Location	ppm N in Soil	ppm P in Soil
Site 1		
Area 1	1.37	140
Area 2	1.90	182
Area 5	1.44	193
Area 6	1.47	245
Background	0.06	875
Site 2		
Area 1	4.6	171.5
Area 3	3.8	367.5
Area 4	5.4	490.0
Area 5	7.0	280.0
Area 6	12.7	350.0
Background	12.9	52.5
Site 3		
Area 3	<0.1	<0.1
Area 4	<0.1	<0.1
Area 5	<0.1	<0.1
Area 5	< 0.1	<0.1
Area 6	<0.1	<0.1
Background	<0.1	0.8

* Top 25 cm of soil

statistical tests unless otherwise stated. Three different sets of samples were taken over a 12 month period and were analyzed at sites 1 and 2, and two sets of samples at site 3. The site was sampled as described in the section on oil content.

At site 1, Cu, Pb, Ag and Zn were present at levels significantly above background of the top 25 cm. in at least 2 sets of samples. Cr and Ni showed up as significant in one set of samples. The data is presented in Appendix B. Table 7.11 lists the metals found at significant levels above background at all three sites. No samples from the 25-51 cm zone showed significantly increased metals concentrations at a 95% confidence level.

At site 2, samples collected in 1981 showed some metals at levels significantly above background, but the sample collected in 1982 showed no significant increase in metal concentration of either the top or bottom zones. Co, Ni and Al showed up at elevated concentrations in all 3 sets of top samples while Cu, Co and Al show up at elevated concentrations in two sets of bottom samples.

At site 3 only chromium shows up at concentrations above background in both sets of top samples.

The raw metals data is listed in Appendix B.

Even though several metals were found at concentrations significantly above background in both top and bottom samples, the concentration in the soil was not necessarily very high. At site 1, the concentration of Cd, Ni, Ag, Co were all less than 30 mg/kg, with Cd generally at a concentration of 1 mg/kg N less.

At site 2, all metals were present at low concentrations, with the exception of Al. High Al concentrations are to be expected, since the soil contains clay. Thus, even though there are several elements present at concentrations above background, this is not very signifi-

TABLE 7.11 METALS FOUND AT CONCENTRATIONS SIGNIFICANTLY ABOVE BACKGROUND

Site 1

Date	α =.05		α =.1	
	Top	Bottom	Top	Bottom
7/28/81	Cu Pb Zn Ag		Co	Al
11/10/81	Cu Pb Zn Cr Ag			Cr
6/14/82	Ni Pb		Cu	

Site 2

Date	α =.05		α =.1	
	Top	Bottom	Top	Bottom
7/21/81	Co Ni Al	Cu Co Al Cr Ag	Pb Zn Cr	Zn Ag
11/28/81	Cu Co Ni Pb As Al Cr Ag	Cu Co Pb Zn Al Ni		As Al Cr
6/16/82	Co Al Ni			

(continued)

TABLE 7.11 (continued)

Site 3

Date	α =.05		α =.1	
	Top	Bottom	Top	Bottom
11/17/81	Cr	Pb	As	Cu
		Zn	Cu	Ni
		Al	Pb	Cr
			Zn	Ag
6/29/82	Zn	Zn		
	Cr	Ni		

cant.

At site 3, where chromium and zinc show up at levels significantly above background, the actual soil concentrations are in the 65 mg/kg range for chromuim and 100 mg/kg range for zinc. Similarly, the concentration of metals Pb, Zn and Al in the bottom samples, even though higher than background, are not very high.

pH

The pH of the top (0-25 cm) and the bottom (25-51 cm) of site soil were determined during the project to see if the potential for solubilization of metals existed at the sites. The mean site concentrations are presented in Table 7.12. The pH values at all the sites are above the recommended 6.5 except for site 2 on 7/21/81, where the pH was 6.4. However later pH readings at this site yielded values of 7.2, which is well above the value of 6.5 recommended to minimize metal solubilization.

Chloride

The chloride ion concentrations of the site soil was significantly higher than background at all three sites. Only 1 set of determinations were made, therefore, variation over time could not be observed. However, the chloride ion concentration of the soil pore water did decrease over time, and the same trend could be expected for soil chloride ion concentration. Table 7.13 shows the mean chloride ion concentrations at the three sites.

Total Organic Carbon

The average Total Organic Carbon (TOC) values for the sites are given in Table 7.14. The TOC values of the top (0-25 cm) of soil at sites 1 and 3 are significantly greater than background. The bottom (25-51 cm) sample at site 3 is also greater than background. At site 2 the top sample of 11/12/81 is significantly greater than

TABLE 7.12 SITE pH VALUES

Date	Mean pH Values Top	Bottom	Bkg Top	Bkg Bottom
Site 1				
11/10/81	7.4	-	-	-
12/1/82	7.1	7.4	7.4	7.5
Site 2				
7/21/81	6.4	6.6	6.8	6.8
11/12/81	7.2	-	7.0	-
11/19/82	7.2	7.3	7.2	7.8
Site 3				
7/16/81	7.4	6.7	5.8	-
11/17/81	7.4	-	7.2	-
3/26/82	7.5	-	-	-

TABLE 7.13 SOIL CHLORIDE CONCENTRATION

Date	Mean Cl^- Concentration (mg/kg) Top	Bottom	Bkg T	Bkg B
Site 1				
6/30/82	119.6	103.3	17.6	15.4
Site 2				
7/8/82	28.0	33.1	13.7	2.9
Site 3				
11/4/82	72.6	101.5*	19.8	7.3

* Mean of 2 determinations

background top sample. Sites with higher oil content have correspondingly high TOC values. These TOC values were determined using the Walkley-Black dichromate oxidation method taken from methods of Soil Analysis edited by Black et al.. The oil at site 3 extended well below the zone of incorporation, hence the high TOC values of the bottom sample at site 3. There was not nearly as much penetration of oil at sites 1 and 2, hence the relatively low TOC values of the bottom samples from these sites.

UNSATURATED ZONE MONITORING

The unsaturated zone at each of the three sites was monitored for evidence of the presence of pollutants. The objective was to determine whether or not pollutants were migrating below the zone of incorporation. This monitoring was accomplished by taking core samples below the zone of incorporation at depths between 51 cm and 152 cm (20-60 inches), and by collecting samples of the soil pore water passing through the unsaturated zone using soil moisture samplers.

The soil core and soil pore water samples were analyzed for:

(1) oil content
(2) heavy metals
(3) organics

In addition to these tests, some soil pore water samples were analyzed for:

(1) chloride
(2) pH
(3) conductivity
(4) COD and/or TOC

TABLE 7.14 SOIL TOC

Date	Top	Mean TOC % Bottom	Bkg T	Bkg B
Site 1				
11/10/81	10.4	1.5*	2.0	1.3
Site 2				
7/21/81	3.6	2.6	1.1	0.5
11/12/81	5.2	0.9	0.8	0.3
Site 3				
11/17/81	11.2	6.7	1.4	0.3

* Mean of 2 values

SOIL PORE WATER ANALYTICAL RESULTS

Organic Priority Pollutants

Samples of soil pore water were analyzed for the B/N and phenolics as listed in Table 7.1. Samples from site 1 indicated the presence of 5 organic compounds in the soil water. These compounds were phenol, bis(2-ethylhexyl) phthalate, di-n-butylphthalate, butylbenzylphthalate and chrysene. Bis(2-ethylhexyl)phthalate showed up at concentrations of 120.8 and 55.64 mg/l in two samples. Three samples of soil pore water from site 1 were analyzed.

At site 2, a total of 5 samples were analyzed for priority pollutants, with only two samples showing the presence of any. The compounds found were phenol, chlorophenol and pentachlorophenol, all present at levels of less than 1 ppt. Only 1 sample of those analyzed at site 3 showed any organics present, and this was at a concentration of less than 1 ppt.

Background soil pore water samples were analyzed from sites 2 and 3, and no priority pollutants were found in these samples. No background soil water samples were obtained from site 1. Table 7.15 lists the organic priority pollutant identified at the sites. The concentrations of the compounds identified at the sites are given in Tables B-5 to B-7, Appendix B.

Metals

Tables 7.16 - 7.18 show the concentrations of metals found in the soil pore water. At site 1, barium was present in some samples at levels greater than the drinking water standards. Arsenic was present in two samples from one sampler at levels near the drinking water standard of 0.05 mg/l. Iron and manganese were present at quite high concentrations. Iron concentrations ranged from 0.20 to 11.99 mg/l, while manganese

TABLE 7.15 PRIORITY POLLUTANTS PRESENT IN SOIL PORE WATER

Compound	Site 1	Site 2	Site 3
Phenol	x	x	x
4-Nitrophenol		x	
Pentachlorophenol		x	
Chrysene	x		
Bis(2-ethylhexyl)phthalate	x		
Di-n-butylphthalate	x		

TABLE 7.16 SOIL PORE WATER (mg/l) METALS (Site 1)

	Ag	Al	As	Ba	Cd	Cr	Cu	Ni	Pb	Zn	Fe	Mn
6/14/82												
Area 1	.008	.06	.042	5.28	<.001	.060	0.02	.04	<.02	1.44	5.81	1.70
Area 3	.011	.71	<.001	.58	<.001	.060	0.01	.028	<.02	.35	0.20	.12
Area 6	.010	.04	-	1.28	<.001	-	0.04	.036	<.02	.75	10.31	3.53
12/1/82												
Area 1	.011	.53	.089	2.13	<.001	.030	<.002	.035	<.02	2.44	4.62	1.32
Area 4	.011	0.80	.024	1.24	<.001	.060	.010	.035	<.02	.84	3.88	1.37
1/13/83												
Area 4	.021	0.09	-	2.15	-	.050	<.002	.08	0.20	.14	0.70	8.0
Area 6	.020	0.04	-	3.50	.001	.040	.01	.09	<.02	.04	11.99	12.00

TABLE 7.17 SOIL PORE WATER (mg/l) METALS (SITE2)

	Ag	Al	As	Ba	Cd	Cr	Cu	Ni	Pb	Zn	Fe	Mn
6/16/82												
Bkg	.006	0.58	<.001	.88	<.001	.050	.04	.001	<.02	<.001	.49	<.003
Area 6U	.009	0.85	0.140	.88	<.001	.070	.04	.023	<.02	0.73	4.44	34.600
Area 3	.013	0.42	.061	4.63	<.001	.030	.08	.048	<.02	1.04	.33	.006
Area 6T	.012	0.56	.028	.88	<.001	.030	.03	.015	<.02	4.34	.06	.253
11/19/82												
Area 5T	.012	0.59	.060	.70	<.001	.040	.06	<.001	<.02	0.07	1.38	1.090
4/11/83												
Area 3	.035	0.29	-	3.82	<.001	.030	.02	.50	0.44	0.08	.09	<.003

TABLE 7.18 SOIL PORE WATER (mg/l) METALS (SITE 3)

	Ag	Al	As	Ba	Cd	Cr	Cu	Ni	Pb	Zn	Fe	Mn
6/15/82												
Bkg	.077	<.02	-	.77	<.001	.010	<.02	.208	.02	.49	.551	.463
Area 2	.022	.23	.054	2.53	<.001	.010	.02	.073	<.02	2.84	.964	7.31
Area 5	.044	.26	-	6.63	<.001	.040	.04	.429	<.02	.74	3.594	32.40
3/8/83												
Bkg	.026	.28	-	.62	<.001	.010	.05	.34	<.02	.08	.060	.01
Area 2	.043	.35	-	4.32	<.001	.070	.02	.40	<.02	.08	2.090	20.19

concentrations ranged from 0.12 to 12.00 mg/l.

At site 2, most metal concentrations in the site soil pore water samples were a little higher than those in the background soil pore water samples. However, with the exception of a few values for barium, zinc, iron and manganese, the concentrations were not higher than the drinking water standards. Barium concentrations of 3.82 and 4.63 mg/l were found in two samples collected from the same sampler at the site. As with site 1 samples, the values of iron were elevated, ranging from 0.09 to 4.44 mg/l, with a background value of 0.49 mg/l. The manganese values ranged from <0.01 to 34.60 mg/l. The 34.6 value seemed very high, but duplicate analyses yielded similar values.

At site 3, as with the other sites, only the barium, zinc, iron and manganese values were significantly higher than background. The manganese values were particularly high, with two different samples from the same area giving concentrations of 7.31 and 20.19 mg/l. Another sample from a different area, contained 32.4 mg/l of manganese.

pH

At site 1 only one set of pH values was obtained and these were all around 7. At site 2 the pH values of samples, taken at different times, ranged from 6.4 to 7.4. At site 3, pH values of soil water taken at different times again ranged from 6.4 to 7.4.

Chloride ion

The chloride ion concentration of the soil pore water at the sites is shown in Table 7.19. The concentrations at sites 1 and 3 were appreciably higher than the concentrations at site 2. The results indicated a decrease in the chloride ion concentration with time, with the sites with higher oil concentrations having

TABLE 7.19 SOIL PORE WATER

CHLORIDE ION CONCENTRATION (mg/l)

Site 1

Date	Location Area 1	Area 3	Area 4	Area 6
6/14/82	655.1	600.5	-	701.0
8/4/82	-	522.3	-	-
12/1/82	395.6	-	-	-
1/13/83	-	-	372	364.9

Site 2

Date	Location Bkg	Area 3	Area 5	Area 6 (untilled)	Area 6 (tilled)
6/16/82	14.6	82.1	-	137.9	61.9
7/8/82	13.2	52.8	11.5	65.8	21.8
11/19/82	-	-	-	-	24.9
2/16/83	-	-	20.5	30.8	-
4/11/83	-	21.7	-	-	-

Site 3

Date	Location Bkg	Area 2	Area 4	Area 5
6/15/82	112.8	1056.4	-	5147.4
10/19/82	-	759.0	-	-
3/3/83	40.9	486.5	-	-
6/7/83	28.7	434.9	-	2129.3

- No sample obtained on this date or no analysis performed because of insufficient sample higher chloride ion concentrations.

This shows that sites with high oil loading rates can leach significant amounts of chloride ion for a considerable period of time. No oil had been applied to site 2 since 1976, and the chloride ion concentration was low, while at sites 1 and 3, where the chloride ion was much higher, oil had been applied at high loading rates up until the beginning of 1981.

COD/TOC

The soil pore water contained oxidizable material at quite high levels when compared to backgound. At site 1, the COD values ranged from 400 mg/l to 2420 mg/l when the first COD samples were analyzed. Six months later, the highest concentration was 1690 mg/l. TOC values were consistently lower than COD values, by a factor of about 3. Three TOC values taken from one location at this site, indicated a decrease in TOC with time.

Site 2 showed similar trends, with a COD/TOC ratio of about 3:1. Again there was a decrease in the TOC values with time. The COD values also decreased. The amount of organic carbon present was lower than at site 1, as would be expected from the lower oil content values at site 2. Values ranged from 335 mg/l to 990 mg/l for COD on the first set of samples with a background value of 13 mg/l.

Site 3 samples showed a general trend of increasing COD at the 2 locations where several samples were collected over a 12 month period. Again a COD/TOC ratio of approximately 3:1 was observed. Tables 7.20 - 7.22 present the pH, COD, TOC and conductivity values of soil pore water samples. This data is presented graphically in Figures 7.1 - 7.7.

TABLE 7.20 SOIL PORE WATER CHARACTERISTICS SITE 1

Date	Location	pH	COD (mg/l as O_2)	TOC (as C)	Conductivity (µmhos/cm at 25°C)
6/14/82	Area 1	7.2	1580	458	-
	Area 3	7.0	400	110	-
	Area 6	7.2	2420	751	-
12/1/82	Area 1	-	1000	306	-
	Area 4	-	1000	-	-
	Area 6	-	1690	503.1	-
1/13/83	Area 6	-	-	488.7	-

TABLE 7.21 SOIL PORE WATER CHARACTERISTICS SITE 2

Date	Location	pH	COD (mg/l as O_2)	TOC (as C)	Conductivity (μmhos/cm at 25°C)
6/16/82	Bkg	-	13.	8.0	-
	Area 3	7.2	990	303.0	-
	Area 6U	7.0	750	232.0	-
	Area 6T	6.9	335	102.0	-
7/8/82	Bkg	7.1	50	8.0	-
	Area 3	6.8	960	300.0	-
	Area 5	7.4	235	-	-
	Area 6U	6.8	665	198.0	-
	Area 6T	6.9	300	86.0	-
11/19/82	Area 6U	-	770	-	
	Area 6T	-	460	-	
2/16/83	Area 3	6.6	-	243.3	2400
	Area 5	6.4	-	84.6	900
	Area 6U	6.6	-	187.5	2000
4/11/83	Area 3	6.8	560	212.4	-
	Area 5	6.5	325	108.8	-

TABLE 7.22 SOIL PORE WATER CHARACTERISTICS SITE 3

Date	Location	pH	COD (mg/l as O_2)	TOC (as C)	Conductivity (μmhos/cm at 25°C)
6/15/82	Bkg	6.8	93	41	-
	Area 2	7.3	440	117	-
	Area 4	6.6	850	204	-
10/19/82	Area 2	7.0	615	-	-
	Area 5	6.4	740	-	-
3/8/83	Bkg	7.0	90	32.8	1020
	Area 2	7.3	610	189.9	1700
	Area 5	-	630	-	-
5/2/83	Bkg	6.4	60	27.1	-
	Area 2	6.6	1180	352.9	-
	Area 5	-	750	-	-
6/7/83	Bkg	6.8	125	23.7	1000
	Area 2	6.8	1220	383.3	3500
	Area 5	7.4	850	-	-

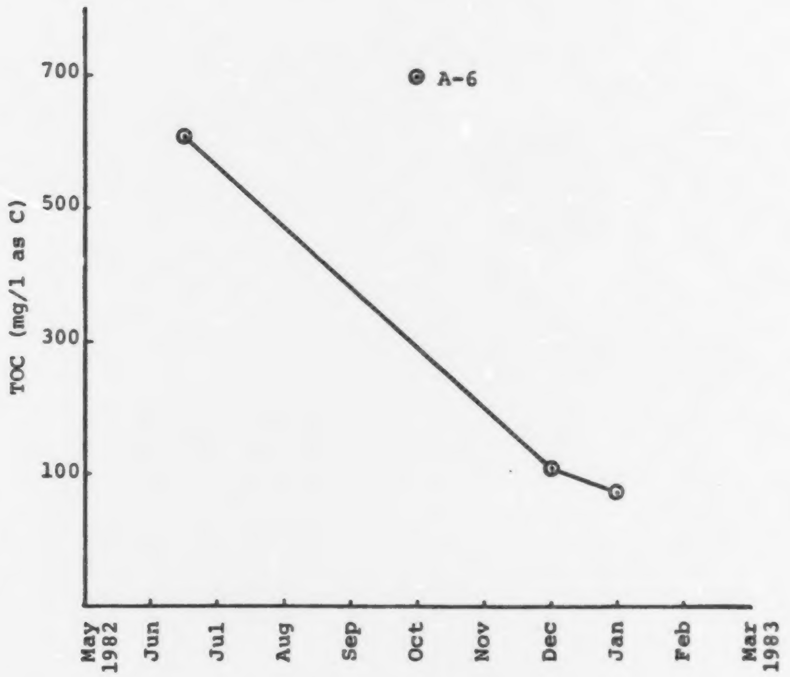


Figure 7.1 Graph of T.O.C. vs time for site 1 soil moisture samples

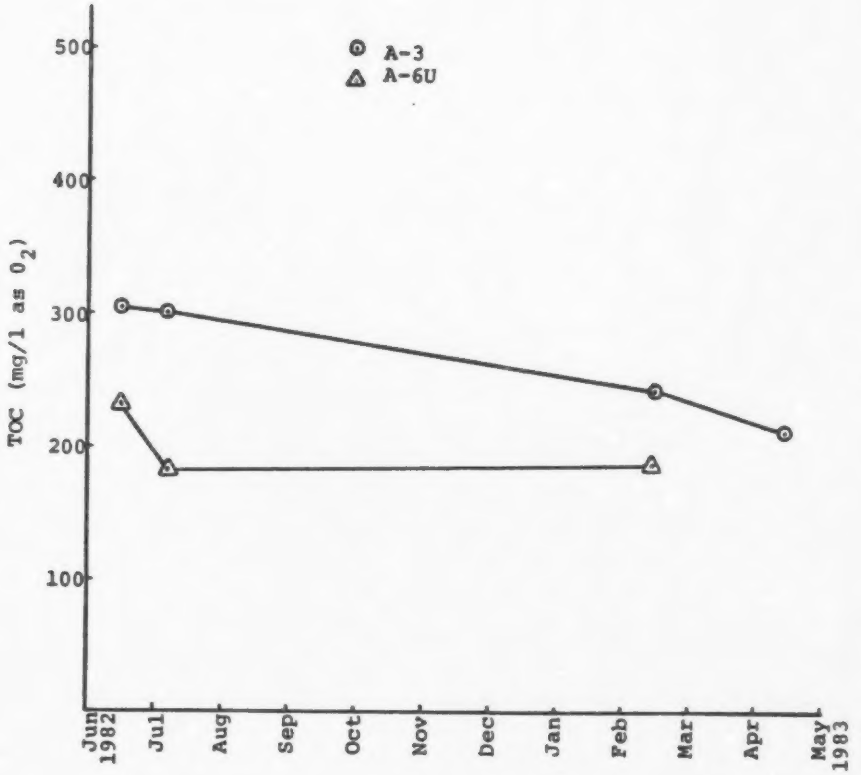


Figure 7.2 Graph of T.O.C. vs time for site 2 soil moisture samples

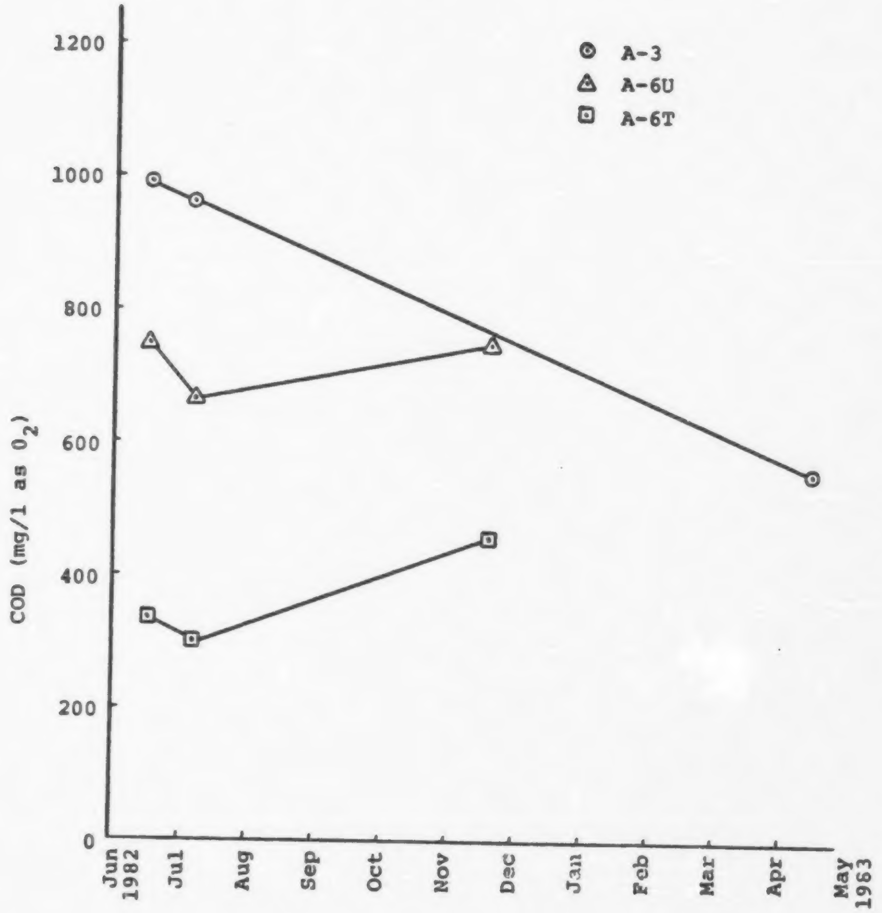


Figure 7.3 Graph of C.O.D. vs time for site 2 soil moisture samples

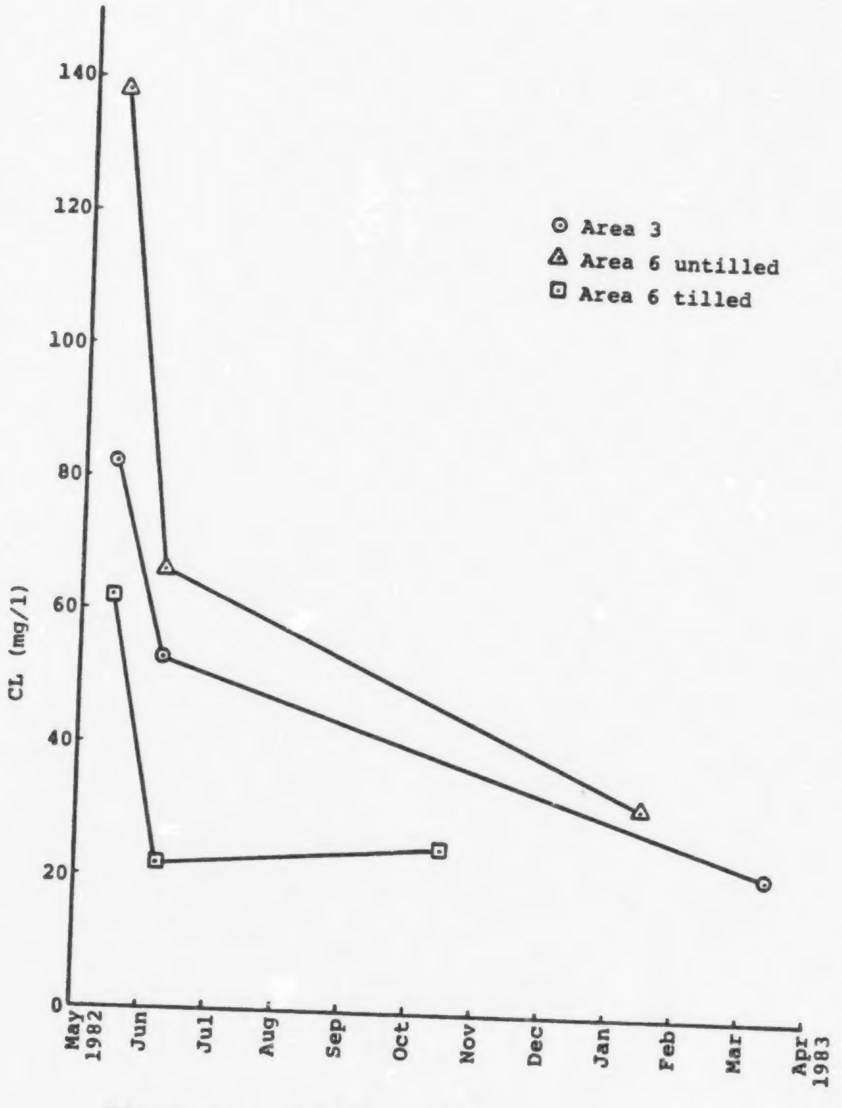


Figure 7.4 Graph of Cl vs time for site 2 soil moisture samples

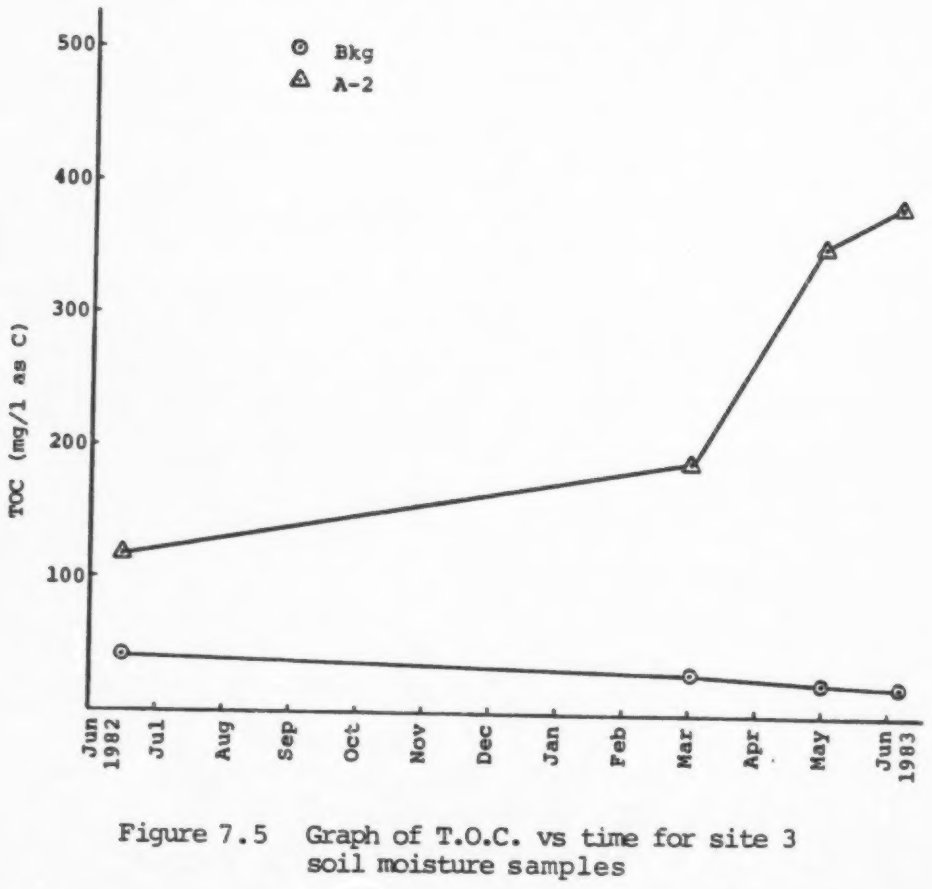


Figure 7.5 Graph of T.O.C. vs time for site 3 soil moisture samples

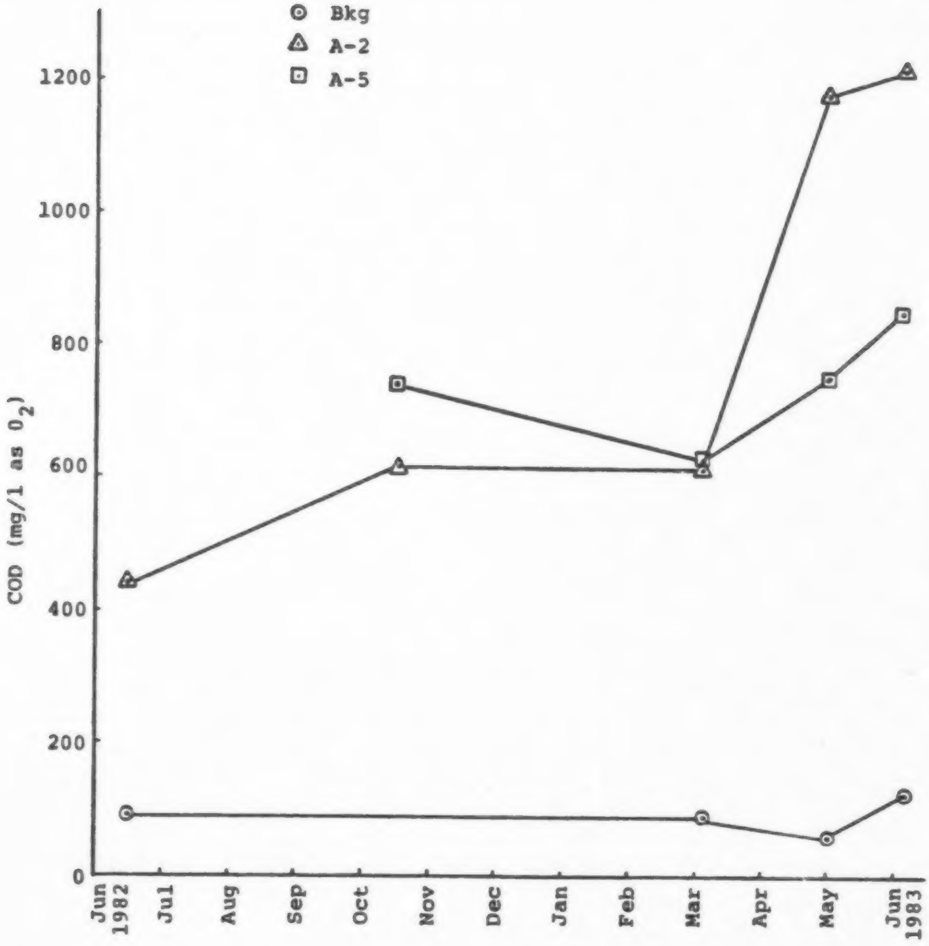


Figure 7.6 Graph of C.O.D. vs time for site 3 soil moisture samples

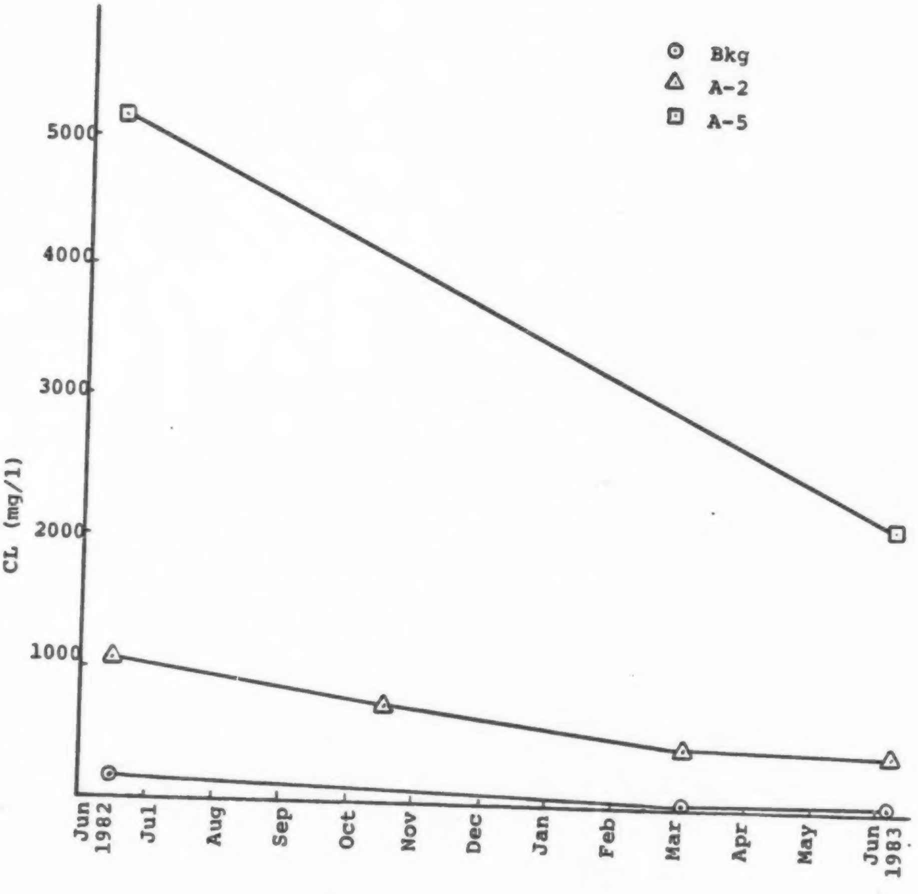


Figure 7.7 Graph of Cl vs time for site 3 soil moisture samples

Oil Content

Table 7.23 shows oil content values for some soil pore water samples from each of the three sites. There does not appear to be much correlation between the oil content and the TOC/COD values for the soil pore water. The sample from area 3 at site 2 had an oil content of 0.8 mg/l and a TOC of 2433 mg/l, while the sample from area 6 at site 1, had an oil content of 133.2 mg/l and a TOC of 488.7 mg/l.

The values show that oil can be leached from the top layers of the soil for some time after application of residues has ceased at a site.

TABLE 7.23 OIL CONTENT OF SOIL PORE WATER

Site No.	Location	Date	Oil Content (mg/l)
1	Area 1	12/1/82	60.7
1	Area 6	12/1/82	73.0
1	Area 6	1/13/83	133.2
2	Bkg	7/8/82	<0.1
2	Area 3	2/16/83	0.8
2	Area 6 U*	2/16/83	71.4
3	Bkg	3/8/83	<0.1
3	Area 2	3/8/83	13.2

* U - untilled.

DEEP CORE ANALYTICAL RESULTS

Deep cores refer to samples taken below 51 cm depth. These samples were analyzed for oil content, metals and priority pollutants as a part of the unsaturated zone monitoring program.

Oil Content

The oil content of the deep cores taken at the sites with the exception of 2 samples at site 2 and at site 1, were all less than 0.1%, indicating that no oil had migrated below 51 cm. At site 2, two samples from area 6 had oil content values of 0.21 and 0.24%. Site 2 was the most permeable of the 3 sites, and area 6 was the area at site 2 with the highest oil content. Thus, it is possible that oil might have reached the 124 cm (49 inches) depth. The high value at site 1 was in area 1, which had the lowest oil content at the site. It appears that this value was an outlier, since all other concentrations were very low, and the permeability of the site soil was very low. The oil content data is presented in Table 7.24.

Priority Pollutants

A number of organic priority pollutants were identified in the core samples at the unsaturated zone at the three sites. Table 7.25 lists the compounds identified at the sites. No compounds were found at all three sites, only 5 were found at 2 sites, and all other compounds at only one site. Anthracene, 1,2-Diphenylhyrazine, Bis(2-ethylhexyl)phthalate, Butylbenzylphthalate and 2,4-Dichlorophenol were the compounds found at 2 sites.

Priority pollutants were also found in the background cores at the sites. 1,2-Diphenylhydrazine was found at site 1 and phenol at site 3. Site 2 background cores contained 5 compounds. The area from which background cores were taken at site 2, was contaminated with oil after the project started. This may be the reason for some of the anomalous results obtained with background samples taken from this area.

Concentrations of the compounds identified in the analysis of the deep cores are given in Tables B-5 through B-8, Appendix B. These concentrations are not absolute, but represent rough guides, since no study on recoveries of organics from soil matrices was performed.

TABLE 7.24 OIL CONTENT DATA FOR DEEP CORES

Date	Location/Depth(cm)	Oil Content(%)
Site 1		
12/30/81	2(114-127)	.02
	3(81-122)	.01
	6(81-104)	.03
6/30/82	Bkg(102-112)	.05
	Bkg(152-168)	.11
	1(127-141)	.74
	6(107-117)	.06
	6(152-163)	.05
Site 2		
12/21/81	3(66-76)	.03
	3(76-91)	.02
	3(91-102)	.02
	5(66-91)	.00
	5(124-152)	.00
	6(66-81)	.21
	6(81-124)	.24
	6(124-147)	.04
7/8/82	2(84-94)	.04
	4(86-102)	.03
	4(127-137)	.02
	6(127-147)	.02
	Bkg(76-107)	.07
	Bkg(142-157)	.04
Site 3		
12/28/81	2(76-91)	.03
	3(81-91)	.01
	5(69-76)	.02
6/29/82	Bkg(76-89)	.03
	Bkg(117-130)	.05
	2(114-122)	.02
	6(132-142)	.03

TABLE 7.25 PRIORITY POLLUTANTS PRESENT IN UNSATURATED ZONE CORES

Compound	Site 1	Site 2	Site 3
Acenaphthene	x		
1.2-Disphenylhydrazine	x	x	
2,4 Dinitrotoluene	x		
Anthracene		x	x
Bis(2-ethylhexyl)phthalate		x	x
Isophorone		x	
Acenaphthylene		x	
Fluorene		x	
Diethylphthalate		x	
Butylbenzylphthalate		x	x
2-Nitrophenol		x	
4-Nitrophenol		x	
2.4-Dichlorophenol		x	x
Phenol		x	
Phenanthrene			x
Pyrene			x
Chrysene			x
Benzo(a)anthracene			x
Benzo(b)fluoranthene			x
Benzo(k)fluoranthene			x
Benzo(a)pyrene			x
2,6-Dinitrotoluene			x
Di-n-butylphthalate			x

Metals

The metal concentrations in the deep cores were not significantly above background concentrations, except for the nickel concentrations in both the first set of cores from the (127-152) cm depth at site 1, and the first set of cores from the (114-142) cm depth at site 3. However, the concentrations were quite low, 33 and 49 mg/kg at site 1 and 3, respectively. Thus, it appears that no buildup of metals occurred in the unsaturated zone. The raw metal data is given in Table C-6, and the mean concentrations in Table C-7, in Appendix C.

Discussion of Results

Monitoring of the unsaturated zone at these three sites revealed some interesting facts. The water passing through the unsaturated zone contained high amounts of chloride, and appreciable amounts of Freon extractable compounds (oil and grease). Some metals are apparently solubilized under the conditions which exist at these sites. Even though the pH of the soil pore water and the pH of the soil in the top 51 cm (20 inches) were both above 6.5 (usually above 7.0), barium, zinc, iron and manganese were found at fairly high concentrations, especially iron and manganese, in the soil pore water. Further monitoring of soil pore water at land treatment sites is necessary to verify these results.

No evidence of migration of oil into the soil of the unsaturated zone (below 50 cm) was found. However the results suggest that there is some movement of organic priority pollutants into the unsaturated zone. It must be stressed that the quantitative values presented for these priority polluants are intended as guides only, since no work on recovery of organics from soil matrices was performed. The deep soil cores contained more compounds than the soil pore water. Whether this may due to better recoveries from the soil matrices as opposed to the aqueous phase, or to the absence of these compounds in the aqueous phase has not been determined.

The soil pore water also showed levels of TOC and COD much above background at all sites. However, it appears that the oxidizable material present may have a large inorganic component, since the TOC/COD values at site 2 are in the same range as those at site 3, where the soil organic content is very much higher. If the oxidizable material were primarily organic, one would expect site 3 to have much higher TOC/COD values than site 2.

At site 2, where the soil moisture samplers were located under tilled and untilled sections of area 6, the TOC, COD and Cl^- concentrations, as presented in Figures 7.3-7.5, are higher under the untilled area than under the tilled area.

This suggests that tilling the soil does have the effect of reducing the concentration of substances in the soil pore water. This is probably because the permeability of the tilled area is increased, resulting in less leaching of the till zone by infiltrating water. This results in lower contaminant concentration in the soil pore water, since most of the contaminants are in the till zone.

SECTION 8

EMISSIONS STUDY

During the course of the closure study, it was observed that after tilling the soil at the landfarm sites, a strong smell of hydrocarbons was present in the tilled areas. It was decided to attempt to determine whether significant levels of hydrocarbons were being emitted from the site as a result of the tilling operation. A hydrocarbon monitor called a Bacharach TLV-Sniffer was used. This is not a standard procedure, but has been used by Radian Corporation to assess emissions from the land treatment of oily sludges. The TLV Sniffer has a sensitivity range from 1 to 10,000 ppm of gas. The Sniffer functions by catalytically oxidizing the gas in the air sample. The catalyst is coated on an element whose resistance charges with the amount of oxidized gas, and this change in resistance is compared to an identical element not subject to oxidized gas. An electrical signal is generated, which depends on the difference in resistance between the two elements, which in turn depends on the amount of hydrocarbon present originally. Table 8.1 presents data obtained by using the Sniffer at sites 1 and 3 on background soil, and site soil before and after tilling. It should be noted that the soil at site 1 was fairly wet when these readings were taken, while at site 3 the site was dry. At site 1, the soil was too wet to till, and so readings were taken from a section of the site which had been tilled before, and a section which

TABLE 8.1 CONC. OF HYDROCARBONS EMITTED AT SITES 1 AND 3

Location	Hydrocarbons Emitted ($mg/hr/M^2$)
Site 1, Control Area	1.2
Site 1, Untilled Area	1.2
Site 1, Tilled Area	1.7
Site 3, Background	1.2
Site 3, Before Tilling	10.2
Site 3, After Tilling	25.2

Site 1 - Site soil was wet

Site 2 - Site soil was dry

had never been tilled. At site 3 the same area was tested before and after tilling.

The results obtained from site 3, which had not had any residues applied for 18 months when these readings were taken, suggest that hydrocarbons are emitted from a land treatment site for a long time after application of residues, and that tilling increases the rate of these emissions. The data from site 1 suggests no appreciable increase in emissions occurs. However, the soil at site 1 was wet and could not be tilled just prior to taking the readings. This could have affected the quantity of hydrocarbons emitted from the tilled area.

SECTION 9

RUNOFF STUDY

The objective of this study was to determine whether runoff from closed land treatment sites contained any selected hazardous constituents. To carry out this study, a wooden frame was installed at each site. This frame consisted of four (4) 2 x 12 pieces of board 3.7 meters (12 feet), connected together to form a square with one end open. The open end was attached to a metal flume 5 cm. (2 inches) wide, 15 cm. (6 inches) deep and 1 meter (38 inches) long. The frame was installed at each site so that the corner with the flume was down slope, so that any rain which fell inside the flume would run off towards the open end to which the flume was attached.

Water was then applied inside the frame in the form of a spray, to simulate the 25 year, 24 hour storm for the particular area in Oklahoma. Site one received the equivalent of 15 cm. (6 inches), and sites 2 and 3 received 18 cm. (7 inches), since these were the amounts that would be the equivalent of the 25 year, 24 hour storm as obtained from Technical Paper No. 40, published by the Weather Bureau (Hersfield, 1981). The water was applied over a period of about two hours, and the runoff collected at fixed intervals until the runoff stopped, and composited. Samples from the composite were then analyzed for

(1) priority pollutants (2) metals
(3) oil content

(4) COD/TOC

Table 9.1 shows the COD/TOC values, Table 9.2 oil and grease and Table 9.3 metals shown to be present in the runoff from the three sites.

TABLE 9.1 COD/TOC CONC. OF RUNOFF

Site No.	COD (mg/l as O_2)	TOC (mg/l as C)
1	120	18
2	5	<5
3	540	495

The runoff area at site 1 was untilled with no grass, site 2 was grass covered, site 3 was tilled with no grass cover. Runoff started at sites 1 and 2, which were untilled, quite soon after application of the spray water. However, at site 3, which was tilled, it took much longer for runoff to start, and the color of the runoff was much darker than at either of the other two sites.

TABLE 9.2 OIL AND GREASE CONCENTRATION OF RUNOFF

Location	Oil and Grease mg/l
Site 1, Runoff	8.4
Site 2, Runoff	10.8
Site 3, Runoff	35.8

Results and Discussion

The color of the runoff from site 3 was brownish, with suspended particulate material. The runoff from

TABLE 9.3 METAL CONCENTRATIONS IN RUNOFF WATER

	Ag	Al	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Site 1										
Applied water	0.015	.04	<.01	.04	.05	.150	<.003	.010	<.02	<.001
Runoff 1	.019	1.63	<.01	.09	.09	1.863	.008	.046	<.02	<.001
Runoff 2	.025	1.19	<.01	<.003	.10	0.830	.011	<.008	.02	.050
Site 2										
Applied water	.006	.09	<.01	<.003	.01	< .005	< .008	< .02	< .02	.34
Runoff 1	.013	0.07	<.01	.04	.01	.323	.033	<.008	<.02	.060
Runoff 2	.017	.28	<.01	<.003	.01	.294	2.72	<.008	<.02	.220
Site 3										
Applied water	.019	.19	<.01	.02	.01	.050	.020	.045	0.17	<.001
Runoff 1	.004	.86	<.01	.01	<.002	.490	1.51	<.008	<.02	<.001
Runoff 2	.005	.34	<.01	<.003	.01	.373	.021	<.008	<.02	<.001

site 2 was almost colorless with little suspended material. The runoff from site 3 was a pale brown color, with suspended particulate material.

The COD and oil and grease data indicate that the runoff from tilled areas without grass cover contains more organic material than runoff from untilled areas without grass cover. Even though the oil content of the areas under study at site 1 (≅8%) and site 3 (≅14%) was appreciably different, the reason for the difference in the concentrations of oil and grease and COD of the runoff from these sites, appears to be the longer time that it takes to get runoff at site 3. Here the soil was tilled, and the water first had to saturate the soil, before runoff could begin, resulting in a darker colored runoff with higher organic concentrations. At site 1 where no tilling had occurred, the soil was compacted, resulting in low infiltration rates and immediate runoff. Site 2 was grass covered, and had a low oil content (≅3%). These factors combined to produce a runoff which was low in organic content.

Duplicate determinations of metal ion concentrations were carried out on samples of the runoff from each site. The concentration of metals in the water applied to the sites was also determined. Table 9.3 lists the results of these analyses. There were differences in the metal ion concentrations between duplicates for some metals. This variation between samples is probably due to the fact that the runoff contained particulate material, and the determinations were made for total metal concentrations. Thus, it is possible that the different samples contained varying amounts of particulate material, despite the fact that the sample containers were thoroughly mixed prior to sampling.

Two metals appeared in the runoff from all three sites at appreciable higher concentrations than in the applied water. These metals are aluminum and iron. The runoff from the sites did not contain any of the organic priority pollutants evaluated (Table 7.1) above detection limits (0.1 ppb). Only base neutrals and phenolics were evaluated. In this particular study, only two of the 11 metals determined showed up at increased concentration levels in the runoff. These metals were aluminum and iron.

SECTION 10

REVEGETATION STUDY

The purpose of the revegetation study was to develop an insight into the process of site closure by studying the effect of oil refinery residues on selected plant species. At the time this study was conducted very little knowledge was available for the closure of sites and no formal guidelines concerning the revegetation of sites existed. Although grasses were the obvious primary choice for revegetation, the OU/EPA cooperative team also agreed that trees should be included in the study in order to determine whether certain species of trees could successfully be grown in the closure and early post closure periods. Trees are useful in minimizing wind erosion and have aesthetic value. Because most trees grow slowly in relation to grass it was felt that an attempt should be made to investigate the feasibility of planting trees as soon as conditions in the closure site permitted.

Species Descriptions

Several species of trees and grasses were selected for field study. The plants which were selected had a number of attributes which made them suitable for revegetation purposes. The most important attribute, common to all species, was their known hardiness.

In addition, trees were selected which have shallow roots in order to reduce the possibility of the roots acting as channels for the contamination of ground water.

Five tree species and four grass species were chosen from a survey of vegetation growing in the state of Oklahoma. Colonial bentgrass, however, was an exception. The selected species are listed below. A brief characterization of each also follows.

Black Locust (Robinia pseudoacacia L.)

The black locust is a member of the Legume family. The natural range of this species is the central Appalachian and Ozark mountains but it has been cultivated widely and now reproduces on its own throughout Eastern North America and parts of the West (Elias 1980). The black locust has been planted extensively in the state of Oklahoma. It can be found in moist woodlands, farm lots, along fences and roads, and in urban environments (Phillips 1959).

Reclamation studies have shown the black locust to be widely adapted to all classes of mine spoils. The black locust has the ability to fix nitrogen and grows rapidly giving quick cover. This species is valuable as a nurse crop for forest planting because it improves soils by adding nitrogen and organic matter. Black locusts can be attacked by the locust borer beetle which results in multiple stem shoots sprouting after the main stem deteriorates (Thames 1977).

Hackberry (Celtis occidentalis L.)

The hackberry tree is a member of the elm family. It is widely distributed in the Eastern United States. The hackberry is adapted to a variety of soils. In Oklahoma it may be found on slopes, rocky hills and bottom lands.

The hackberry frequently grows in limestone soils and on limestone outcrops. In good soils this tree is fast growing and may live up to 200 years. Because of its drought resistance this species is often planted in the Midwest (Elias 1980). The hackberry has good adaptation to disturbed areas (Thames 1977).

Osage Orange (Maclura pomifera (Raf.) Schneid)

The osage orange, "Bodark", is a member of the mulberry family. The native range of this species is uncertain, but it is found from Southwest Arkansas to East Oklahoma and Texas. This tree is widely planted in the Eastern and Northwestern states (Little 1980).

The osage orange is basically a lowland tree that grows best in deep rich bottom lands, but it will tolerate a wide range of soils. In Oklahoma this stout tree is considered to be quite hardy and has been planted as a windbreak and hedgerow species (Phillips 1959).

Red Cedar (Juniperus Virginiana L.)

The eastern red cedar is the most widespread conifer of eastern North America. This species is also the most drought resistant conifer found in the east. The tree is rather slow growing and lives to a moderate age of 200-350 years (Elias 1980).

The red cedar is found scattered throughout the state of Oklahoma in all classes and conditions of soils - from low, wet, swampy areas to dry, rocky ridges containing thin soils. This tree is said to "seemingly thrive on barren soils where few other trees are found" (Phillips 1959). Reclamation studies in the state have shown the red cedar to be especially well adapted to high clay mined land (Thames 1977).

Russian Olive (Elaeagnus angustifolia L.)

The russian olive is a member of the oleaster family. This tree is native to Southern Europe and Central Asia. It was introduced into the United States during colonial times. This tree has been planted and naturalized from New England west to California (Little 1980).

The russian olive is tolerant of soils from salty to alkaline. Because of its dense branches, extreme hardiness and resistance to drought, it has been planted extensively as a windbreak in the prairie states (Elias 1980). The russian olive has good adaptation to disturbed areas and maintains a fairly fast growth rate (Thames 1977).

Bermudagrass (Cynadon dactylon Pers.)

Bermudagrass is a warm season, sod forming, perennial turfgrass which propagates and spreads by stolons as well as by underground rootstalks. Seeding of bermudagrass is dependable only where winters are not extremely cold and there are no prolonged drought periods. For vigorous growth and root development, sodding or sprig planting is the desired method of propagation (Archer and Bunch, 1953).

Introduced from India, bermudagrass grows from Massachusetts to Missouri and Oklahoma. It is cultivated for grazing or lawn use. It is a weed of ditches, vacant lots, roadways, and is well adapted to clayey bottomlands which are occasionally subject to flooding (Gould 1978).

Bermudagrass sod is used extensively for erosion control on streambanks, earthfills and slopes. This species does best on moderately well drained soil and has a wide pH range tolerance. One of the primary uses of bermudagrass in Oklahoma is for revegetation of strip mines. Bermudagrass requires high amounts of nitrogen for superior yields and may become sod bound if not cultivated after four to seven years (Thames 1977).

Colonial Bentgrass (Agrostis tenuis Sibth.)

Colonial bentgrass is a cool season perennial species. It is loosely tufted with short rootstalks and abundant fibrous roots. Mat forming characteristics make this a favorable species for lawns and golf courses. Colonial bentgrass is one of the many bentgrasses common to Great Britain (Vasey 1893).

Colonial bentgrass is able to thrive on lime poor soils in New England and many parts of the northern and middle Atlantic states. This hardy species is most known for its tolerance for heavy metals. Populations of colonial bentgrass have been used for the reclamation of metalliferous mine wastes in England. Bentgrass has been used to reclaim acid and calcareous wastes containing lead, zinc and copper (Smith and Bradshaw, 1979).

Crabgrass (Digitaria Sanguinalis (L.) Scop.)

Large crabgrass is a warm season, shallow-rooted annual species. It reproduces by seed and its tufts increase in size by rooting where the nodes touch the soil. Crabgrass can be found growing in a wide variety of soils throughout the United States, especially in the East and South (Phillips Petroleum 1963).

Crabgrass volunteers well on disturbed soils. It is a common invader on abused native ranges and has been found to be palatable to livestock. Crabgrass prefers well drained conditions and will not survive on water logged soil. This grass is very drought resistant and responds rapidly to precipitation and nitrogen addition (Dalrymple).

Bermudagrass is easily confused with crabgrass. Crabgrass is larger than bermudagrass and tends to sprawl on top of the ground rather than forming dense mats. Crabgrass is the most unpopular lawn and garden weed. It does, however, possess nutritive qualities which make it useful as a forage crop. Watts et al. (1981) found that this species did well on their land treatment site.

Weeping Lovegrass (*Eragrostis curvula*)

Weeping lovegrass is a stout, warm season, perennial bunchgrass with narrow, weeping blades and extensive fibrous roots. This grass was first introduced from South Africa and was planted extensively in the Southwest and Southcentral parts of the United States during 1936 to 1945 where it is well adapted (Archer 1953).

Weeping lovegrass is easily established by seed and spreads by tillering. Young seedlings are vigorous and quickly form a ground cover. This grass is often planted for erosion control and grazing. Weeping lovegrass does well on any type of well drained soil but prefers sandy loam. Good stands can be obtained on soils with undesirable characteristics (Dalrymple 1976).

Weeping lovegrass is one of the best grasses for marginal low potential soils. It does well on low fertility soil but does best on fertile soil. Soil pH has little influence on the adaptation of lovegrass. Weeping lovegrass will grow on acid mine spoils and on soils which are highly basic. This grass is heat and drought resistant but has a higher water requirement when grown on clay soils as opposed to sandy ones. The hardiness of this grass increases with precipitation (Dalrymple 1976).

MATERIALS AND METHODS

Site Characterization

The field studies were conducted on an 11,700 ft^2 section of site 3. The land treatment area of site 3 totaled 7.04 acres. No residues had been placed on the study site for ten months before revegetation tests were conducted. The southern part of the study site contained a higher oil concentration than the northern one and was designated area B. The northern section which had less oil content was designated area A. Thus, a comparison could be made between a lighter and heavier oil content with subsequent effects on revegetation. Lime and fertilizer were applied to the treatment area to satisfy the needs of the plants and soil microorganisms. The fertilizer applications were made as needed at a rate of 300 lb/acre of 10:20:10 or 40-0-0.

The soil in the study area is classified as a clay soil and contains 20% sand, 32% silt and 48% clay. The cation exchange capacity is 14 ce/100cm. All of the soil used for laboratory investigations was taken from the land treatment and control sites.

Trees

Field site 3 was prepared and trees were planted on March 26, 1982. The control site was prepared by first clearing away brush and weeds with a bulldozer and then tilling the soil to a 46 centimeter depth. Care was taken during the cleaning operation to remove as little topsoil as possible. The land treatment area was also tilled to the same depth.

The selected tree species were donated for study by the Oklahoma State Forestry Division. Trees were all in the first year seedling stage. The seedlings were placed in holes which were 46 centimeters deep by 20 centimeters wide. All of the holes were filled upon planting with a mixture of soil from the control area and peat moss, then thoroughly watered.

Trees were spaced at 1.2 meter intervals in rows which ran from north to south for each species. The trees were planted in the following order from west to east: black locust, osage orange, hackberry, russian olive, and red cedar. Herein, the northern part of the land treatment site has been designated area A, the southern part area B, and the control site area C. Forty-five trees, nine of each species, were planted in area A. Fifty trees, ten of each species, were planted in area B and in area C. Individual trees were numbered from north to south, 1-10, for each species.

A thin layer (9,346 cubic centimeters) of an organic mulch (tradename Permagreen) was spread around the base of each tree to counteract some of the ill effects of summer heat. The mulch was applied July 14, 1982 to all trees and was mainly composed of composted cotton plants. A weedeater and lawnmower were employed to control weeds in area C. Photographs were taken periodically to record the development of individual trees.

Measurements of growth were made for each tree through the month of November 1982. November marked a time of natural leaf abscission, at this stage, it was difficult to distinguish a dormant tree from a dead one. The measurements that were taken were for height and basal width were made using a standard tape measure and a vernier caliper. Trees were hand watered to supplement rainfall.

Grasses

Grasses were planted after a long period of heavy spring rains on June 29, 1982. All areas were tilled to a depth of 10 centimeters. In each of the three areas A, B and C, four 1.83 meter by 1.83 meter plots, were marked off and a 1.22 meter space left between each plot. These plots were located adjacent to the tree study areas.

The crabgrass seed that was used was a hardy experimental variety, selection RR-174. Crabgrass seed was donated by the Samuel Roberts Noble Foundation, Ardmore. Weeping lovegrass and colonial bentgrass seeds were purchased from local dealers. The bermudagrass sod was taken from fairly pure stands growing within one mile of the study site.

A 1.9 centimeter layer of commercially processed cow manure was spread on each of the tilled plots. The manure contained 1% total nitrogen, 1% available phosphorous acid and 1% available potassium. Grass seed for all species was broadcast at a rate of 3.4 kg/hectare. A final 0.6 centimeter covering of the manure was spread over the seeds. The bermuda sod was cut with a sod stripper and placed on the prepared manure bed by the solid sodding method. All plots were watered.

Due to unforeseen weather related delays, a second attempt was made to establish the grass plots on July 27, 1982. The techniques employed were basically the same as before with only two exceptions. First, the soil was tilled only to a depth of 1.5 centimeters for all plots prior to seeding. Second, bales of wheat straw were mulched and a thin layer placed over the prepared seed beds.

Visual observations were made to determine if seeds were germinating and maturing. Photographs were taken to assist in monitoring the progress of the study plots during the remainder of the growing season. Samples were analyzed for depth of root penetration by digging up plants with a shovel and measuring the length of the roots.

Environmental Chamber Studies

Environmental chambers were used to provide a controlled environment in which plant responses to soil from areas A, B and C could be studied under optimum conditions. Crabgrass seed and bermudagrass sod were selected because of their ability to survive at the land treatment site.

Soil was collected from each of the three study areas at the field site and placed in 114 liter plastic containers. Dow Fume MC-2 was used to kill extraneous weed seeds in the control soil. This penetrating fumigant contains 98% methylbromide and 2% chloropicrin. The soil was tested for nutrients and oil content as shown in Table 10.6.

Plastic pans which had small drainage holes in the bottom of them served to contain the soil and grass. Crabgrass seed, at a rate of 0.1g/pan, was placed in each of nine pans which were 23x23x7 centimeters. Bermuda sod was placed in the nine deep pans which were 23x23x13 centimeters. Triplicate pans were set up for soils from each of the three areas.

Soil that was placed in the plastic pans was first forced through a 0.95 centimeter sieve. The small pans were filled with soil to within 1.3 centimeter of the top. The deep pans were filled with soil to within 5.1 centimeters of the top.

Based on the results of nutrient analysis, nitrate nitrogen was added to the soils to the equivalent rate of 277 kg/hectare. Nitrogen was added to the soil in each pan by first weighing out the appropriate amount of nitrate nitrogen and diluting it with water and then, spraying the solution onto the soil surface.

The pH of the control soil was slightly lower than the test sites (6.4). Limestone was added to the control soil, in field area prior to planting, as calcium carbonate to bring the pH up to 6.9. The soil in each pan was mixed with water to ensure optimum moisture conditions.

A 1.3 centimeter layer of composted cow manure was spread on top of each pan of soil The crabgrass seed was spread across the top of the manure and a final 0.6 centimeter layer of manure was spread over the seed and watered. The bermudagrass sod was cut from an area adjacent to the field control site. The sod was cut into 15 centimeter by 15 centimeter squares and laid into the deep pans of soil. The sod was pressed down firmly and soil was packed in around the edges of the pans. Finally, sod was thoroughly watered.

Pans with soil from area C were placed in an environmental chamber which was separate from the one that the soil from areas A and B were placed in. Both chambers had an approximate relative humidity of 60% and had temperatures of 28°C for 16 hours of daylight and 22°C for 8 hours of darkness. Incandescent and fluorescent lights were used to provide daylight conditions. The pans were watered as needed throughout the study.

The plants were allowed to grow for two months. During this time period they were measured for height. The above ground biomass was calculated on a dry weight basis via standard procedure.

RESULTS AND DISCUSSION

Field Studies

Trees

Soil samples were collected for oil content analysis at the time when trees and grasses were planted. These samples were collected and composited for each of the areas containing trees and grass. Table 10.1 contains the percent oil content for these locations. The concentrations of oil present at the land treatment site far exceeds the values commonly used in other studies which were reviewed in the literature (Brown 1979, Carr 1919, Giddens 1976, Schwedinger 1968).

TABLE 10.1 OIL CONTENT ANALYSIS

Date	Sample Location	% Oil Content		
		Area A	Area B	Area C
3/26/82	Trees 0-25 cm.	5.3-5.6	9.6-12.8	<0.1
3/26/82	Trees 25-51 cm.	0.0-0.2	0.2-10.7	<0.1
6/29/82	Grass 0-25 cm.	4.1-5.0	14.4-15.4	<0.1

Table 10.2 summarizes the growth measurements for the five tree species planted at the research site. Field measurements for the growth of individual trees appears in Appendix D. When the trees were initially planted there was no significant difference between the size of the trees planted in the land treatment area and those planted in the control area.

During the months of April and May the trees in all three areas appeared to be developing normally. There was one noticeable difference however with the red cedar trees. The cedar trees in area B were pale in color compared to the ones in area C. This distinction became more pronounced as the months passed until finally in August all of the needles were red and dry. In area A the color difference was not noticed until June. The red cedars in area A remained pale green throughout the summer. By September, the branches on most of the cedar trees were a mottled red and green. The cedar trees in area A

TABLE 10.2 MEAN VALUES FOR TREE HEIGHT AND WIDTH

Date	Area	No. Trees	HEIGHT (cm)		WIDTH (cm)	
			Mean	Std. Dev.	Mean	Std. Dev
BLACK LOCUST						
April 7, 1982	A	9	24.122	2.422	0.532	0.209
	B	10	21.490*	6.214	0.336*	0.091
	C	10	27.480	4.739	0.653	0.202
July 27, 1982	A	9	41.267*	16.384	1.048*	0.295
	B	8	21.138*	3.889	0.878*	0.154
	C	10	193.550	40.957	1.824	0.325
Sept. 8, 1982	A	4	49.225	23.216	1.118	0.180
	B	0	--	--	--	--
	C	10	218.850	48.194	2.325	0.591
HACKBERRY						
April 7, 1982	A	9	26.887	6.885	0.302	0.096
	B	10	23.370	5.939	0.256	0.083
	C	10	28.690	7.974	0.350	0.100
July 27, 1982	A	9	20.356*	7.572	0.313	0.093
	B	10	21.260*	6.734	0.233*	0.053
	C	8	34.250	10.866	0.380	0.066
Sept.8, 1982	A	1	29.500	--	0.410	--
	B	1	24.500	--	0.380	--
	C	9	26.233	11.831	0.372	0.060
OSAGE ORANGE						
April 7, 1982	A	9	21.767	5.278	0.988	0.271
	B	10	18.160	3.338	1.031	0.186
	C	10	21.010	5.904	1.190	0.155
July 27, 1982	A	9	20.467*	6.915	0.495*	0.144
	B	8	19.162*	4.579	0.238*	0.063
	C	10	62.550	20.818	0.748	0.134
Sept.8, 1982	A	6	16.600*	6.856	0.550*	0.101
	B	2	7.150*	4.596	0.210*	0.283
	C	10	78.900	30.540	0.869	0.152

(continued)

TABLE 10.2 (continued)

Date	Area	No. Trees	HEIGHT (cm) Mean	HEIGHT (cm) Std. Dev.	WIDTH (cm) Mean	WIDTH (cm) Std. Dev
			RED CEDAR			
April 7, 1982	A	9	31.811	2.970	0.690	0.222
	B	10	33.200	3.752	0.764	0.323
	C	10	34.240	3.555	0.763	0.244
July 27, 1982	A	9	33.922	3.376	0.913	0.488
	B	10	33.770	3.137	0.583	0.215
	C	10	36.150	13.090	0.828	0.292
Sept 8, 1982	A	9	30.833*	2.919	0.788	0.224
	B	10	27.480*	3.635	0.572*	0.192
	C	10	46.000	16.598	0.894	0.318
			RUSSIAN OLIVE			
April 7, 1982	A	9	20.233	7.443	0.726	0.346
	B	10	22.300	6.909	0.654	0.228
	C	10	22.860	4.344	0.544	0.154
July 27, 1982	A	8	23.700*	7.191	0.677	0.432
	B	9	19.200*	4.514	0.643	0.196
	C	8	42.438	16.790	0.651	0.143
Sept. 8, 1982	A	2	21.250	10.960	1.055	0.629
	B	0	--	--	--	--
	C	8	43.312	19.806	0.676	0.182

* statistically significant at 0.05 level when compared to control area C

regained a healthy green color after the winter months passed. All of the red cedar trees in area C remained a deep green throughout the study.

The color differences noted for the cedar trees in the three areas were due to the effects of heat and the amount of oil in the soil. In area B where the oil was heaviest, the plants appeared to be severely dehydrated. The presence of oil in the soil has a negative effect upon the wetting ability of the soil.

The spring months were unseasonably harsh. Heavy wind gusts damaged the tops of some seedlings by removing the leaves, buds, and growing tips. Rain caused minor damage by washing soil up around the base of the trees. Some trees had as much as 13 centimeters of soil piled up around them. Most of the trees adjusted to the change in soil level by putting out adventitious roots. Excess soil was removed with a shovel from around the trees without disturbing the roots. Soil was washed around trees in area C as well as areas A and B; however, the damage was not as extensive. Rainfall data for the study period appears in Appendix E.

Weeds were a problem in area C during the rainy period because they grew to twice the size of the tree seedlings and were in competition with them for nutrients. A weedeater and lawnmower were used to cut back these weeds. One hackberry seedling was accidently cut and killed along with the weeds and one red cedar was shortened.

There were marked changes in the appearance of the trees during the summer months. The data in Table 10.2 indicate that while the number of trees in the control area stayed nearly constant, those in areas A and B decreased for all species. All of the trees were dead in area B at the conclusion of the study with the exception of one red cedar. The trees in area C rapidly increased in size throughout the summer. All of the trees on the land treatment site grew slowly and were severely stunted.

The temperature on the dark colored land treatment site was higher than that for the control site. Some of the trees in areas A and B showed signs of heat stress. Composted cotton mulch seed and hull was spread around the base of each tree in all three areas to lessen the effects of reflected heat. In addition to the high temperatures which the plants had to cope with during the summer, there was an increase in the volatility of the oily waste. On hot days the oily waste was especially odorous and vapors could be seen rising above the soil surface. Daily air temperature data appears in Appendix E.

Leaves which grew 14 centimeters or more above the soil in areas A and B were lost early in the summer. This leaf loss was noted for all of the species with the exception of red cedar. The trees developed new buds and then new leaves within two to five weeks after initial loss. Trees in area B grew back their leaves only once before they succumbed. The trees in area A lost and grew back their leaves anywhere from one to three times. This cycle of leaf loss and regrowth ended in early September. The trees which survived in area A had new basal branches and leaves which were close to the ground. Osage orange and russian olive trees had the most cycles of loss and regrowth of leaves and the largest amount of new growth from the rootstalk.

The cycles of leaf loss and regrowth could have been due to water stress brought about by the presence of the oily waste in the soil. Volatile compounds and heat may also have had an affect on the leaves.

Soil samples were collected to determine if oil was migrating horizontally to the tree roots. Samples were collected from 8 centimeters out around the base of dead trees in areas A and B. The samples were taken to a depth of 25 centimeters from the soil surface. The averaged values for percent oil content are listed below in Table

TABLE 10.3 % OIL CONTENT 8 CENTIMETERS FROM TREE BASE

Date	% Oil Content	
	Area A	Area B
3/26/82	0.00	0.00
6/29/82	0.51	3.65
11/25/82	0.89	4.33

It is apparent from data in Table 10.3 that there was some migration of oil. Casual observation of the roots of dead trees reveals that there were few branch roots present. The values for percent oil content in Table 10.1 indicate that the top 25 centimeters of soil contained more oil than did the 25-51 centimeter depth. The concentration of oil may have affected the root development.

In the control area all of the species grew well with the exception of the hackberry tree. The hackberry seedlings were very small in size from the start of this study and remained small throughout. The seedlings' size could explain the poor growth of this species.

Two russian olive trees faired exceptionally well in area A. The final height and width of these two trees were not significantly different from the russian olive trees in the control area. These two russian olive trees were unique in that they were the only species not significantly different from the controls.

Four black locust trees survived in area A, but they were severely stunted compared to the control trees. Five of the nine red cedar trees planted in area A were also alive. In addition to stunted growth, they were pale in color and many of the needles had turned red and dry. Five osage orange trees showed signs of life in area A. Most of the osage orange trees were so severely stunted that their height and width could not be measured. The parts of the osage orange trees which were alive and green were young shoots and leaves which grew from the root stalks.

The trees growing in area A were unusual in that they were green and had most of their leaves as late as November 25, 1982. The trees in the control had already undergone leaf abscission and were dormant by the first of November. These effects were probably a result of the high soil and air temperatures in the area due to the dark colored soil absorbing heat.

Grasses

The long duration of rain in the spring forced the planting of grass to be delayed until late June. Three weeks after the grass was planted none of the seed had germinated. The seedbed for the grass dried out quickly between waterings. The plots were reseeded in late July.

The straw mulch used for the second attempt to establish grass on the plots helped to hold moisture in the seedbed. The soil was not tilled as deeply for the second seeding as it had been for the first. Shallow tilling depth prior to tilling allowed for more seeds to be kept on the soil surface.

After one month only crabgrass and bermudagrass were growing successfully on the land treatment site. A couple of small isolated lovegrass seedlings were located.

A third unexpected grass was found to be doing well on the plots in areas A and B. This third grass species was barnyardgrass (Echinochloa crusgalli). Barnyardgrass seed had apparently been mixed in with the wheat straw used as mulch. Barnyardgrass is a weed commonly found near the study location.

Barnyardgrass and other weeds were responsible for taking over area C. The presence of additional water stimulated weed growth and most of the seeds planted in the study plots were outcompeted. Crabgrass and bermudagrass, however, fared well in area C.

Poor germination results for many of the seeds under study was attributed to a number of factors. One of these factors was the delay in planting time. The spring months would have been the best time for seeding purposes. Another factor was the thickness of the straw mulch placed over the seedbeds. Wind action piled much of the straw up making germination impossible in some sections of the study plots. A factor which accounted for seed loss was damage caused by a flock of guineas. Since guineas can fly they were able to fly over our control fences and fences over the top of the plots were beyond the scope of this project.

Soil was tested to ensure that there were no nutrient deficiencies which might affect the health of the plants. Fertilizer had been applied in the early spring prior to planting of the trees and grass. Table 10.4 provides the results of the nutrient analysis. Since nitrogen was found to be low in all three study areas, ammonium nitrate fertilizer was applied at a rate of 227 kg/hectare in early September.

The bermudagrass sod which was growing in areas A and B was not as lush and thick, nor as green as compared to area C. Bermudagrass sod on the land treatment site showed a definite edge effect in that all of the edges of the sod which were in contact with the oily sod which were in contact with the oily soil surface were yellow and curling. The center of the sod plots was green and healthy. The sod growing in area B was not as green as the sod in area A. The bermudagrass sod in area C did not have an edge effect and many runners were spread out from the sodded plot. No runners were observed on the plots in the land treatment areas.

TABLE 10.4 NUTRIENT ANALYSIS FOR FIELD SITES

		Kilograms per Hectare				
Area	pH	Available (P_2O_5)	Available (K_2O)	Magnesium	Calcium	NO_3N
A	6.9	180	395	1055	6010	19
B	6.9	75	395	907	4990	16
C	6.6	83	163	1361	2944	12

A few sprigs of bermudagrass were growing in the uncontaminated soil around the base of the trees in areas A and B. These sprigs sent out one to two foot runners. These runners were abnormal because they were not attached to the soil surface. Normally the runners would have roots at each node to secure the plant. Instead, the runners spanning across the soil in areas A and B had only the shriveled up remains of roots at the nodes.

The depth of root penetration was measured on October 19, 1982 for crabgrass, bermudagrass and barnyardgrass to see if root growth was inhibited by the oily waste. Compared with the roots of plants growing in area C there was no difference in the length of roots for any of the species growing in areas A and B. Crabgrass and bermudagrass had roots which penetrated 18 to 20 centimeters into the soil. The barnyardgrass had roots which were between 20 and 26 centimeters long.

Where the grasses were growing, the top 6.1 centimeters of soil in areas A and B was fairly dry. Below this top dry layer the soil was very wet and soggy. Table 10.5 lists the percent oil content for soil samples which were taken to a depth of 15 centimeters. These samples were collected in October from the grass plots.

TABLE 10.5 OIL CONTENT OF GRASS PLOTS

Grass Type	Area A	Area B
Seeded Grasses (Composite of plots)	4.50%	12.25%
Bermudagrass Sod	6.24%	13.22%

In addition to the grasses growing on the plots, three new plant species were discovered on an untilled section of the land treatment site. The first plant was growing in soil which had an oil content of 3.67%. This plant was identified as either *Aster exilius* Ell. or *Aster subulatus* Michx. var. *ligulatus* Shinners. The plant stood about 100 centimeters tall and had roots which penetrated 30 centimeters into the soil. The flowers were unusually small for this species.

The other plants which were growing in the land treatment area were grasses. One of these grasses was *Setaria glauca* (=*S. lutescens*). The roots of *Setaria glauca* penetrated down to 18 centimeters in soil which had an oil content of 4.6%. The second grass was unable to be identified and was most likely an introduced species. The roots of this grass were 13 centimeters long and the oil content of the soil in which it was growing was 1.75%.

Measurements were not taken for the above ground height of the grasses in this study because in late September they were eaten. A large steer had escaped from a nearby ranch and jumped over our 5 foot control fence and was observed eating the grass.

Environmental Chamber Studies

The soil used for study in the environmental chambers was taken from areas A, B and C. An evaluation of the available nutrients, pH, and oil content of this soil appears in Table 10.6.

Water was added to the soil prior to planting to provide adequate moisture for the seeds and sod. The water could not be sprayed directly on the soil surface because it tended to run off and drain through without wetting the soil. The soil was wet by mixing water in with a spoon and stirring vigorously. Once the soil containing the oily waste was wet, it retained moisture for a long period of time.

TABLE 10.6 ENVIRONMENTAL CHAMBER SOIL CHARACTERISTICS

Area	Oil Content	pH	Kilograms per Hectare				
			Available(P_2O_5) Phosphorous	Available(K_2O) Potassium	Mn	Ca	NO_3N **
A	8.7%	6.8	75	299	740	4649	86
B	13.5%	6.8	37	381	646	4763	22
C	0.0%	4.6*	37	245	1701	3515	66

* pH adjusted to 6.9

** Values increased to 227 kg/hectare with NO_3N addition

The germination of crabgrass seed planted in soil from areas A and B was delayed by 7-10 days as compared to seed planted in soil from area C. The crabgrass seedlings growing in the oily soil appeared to be normal the first 10 days after germination. Thirty days after the seed was planted, crabgrass plants in the soil from areas A and B were discolored and severely stunted. The leaves were curled and pale. Some of the crabgrass plants were starting to yellow and the tips of leaves were red. Plants grown in the soil from area C were all green and healthy.

The crabgrass grown in soil from areas A and B had renewed growth 50 days after planting. After most of the leaves appeared to undergo senescence the leaf color improved and new tillers were produced. Table 10.7 lists the mean height values for the plants 40 days and 70 days after they were planted.

In general the crabgrass grown in the environmental chamber, in soil from areas A and B, did not look as vigorous as that which grew at the field site. The difference in appearance could have been the result of exposure to volatile compounds. Wind activity in the field would decrease the amount of exposure that plants would have to volatiles.

TABLE 10.7 MEAN HEIGHT VALUES FOR GRASS

Area of Soil Origin	Height (cm) after Planting 40 days	 70 days
Crabgrass		
A	3.6	3.7
B	1.5	2.6
C	18.0	26.9
Bermudagrass runners		
A	59.8	80.0
B	48.4	70.6
C	95.2	116.9
Bermudagrass sod		
A	20.7	23.0
B	15.9	21.0
C	46.7	38.0

Bermudagrass sod was clipped the day it was planted such that the height of the sod was 7 centimeters and equal for all pans. The runners which grew over the top of the pans were measured along with the thick growth in the center of the sod. Height measurements are located in Table 10.8.

Throughout the study the bermudagrass which grew in the pans containing soil from areas A and B were pale in color and grew slowly as compared to the sod growing in the soil from area C. The above ground biomass was calculated on a dry weight basis for all of the grass seventy days after planting. Total biomass was not calculated because oil adhering to the roots would introduce a large error. The biomass values are listed in Table 10.8.

TABLE 10.8 ABOVE GROUND BIOMASS OF GRASS

Area of Soil Origin	Dry wt (g)	% of Control
Crabgrass		
A	0.46	2.55
B	0.43	2.39
C	18.01	100.00
Bermudagrass		
A	56.47	21.76
B	32.31	38.03
C	148.49	100.00

DISCUSSION

The revegetation of a land treatment site containing large amounts of oil, although possible, is not desirable until much of the oil has been degraded. Soil containing high concentrations of oily waste is more toxic to plants than is soil with low concentrations. Highly oiled soils should be cultivated by tilling, fertilizing, and liming as needed to degrade waste products. The biodegradation of oily waste may actually be slowed with a plant cover present because the soil could not be cultivated. Frequent fertilizer additions necessary to degrade a highly oiled soil may cause injury to plants.

Once the oil has been sufficiently degraded on a land treatment site, revegetation efforts should begin. Vegetation on a land treatment site would serve to protect the soil by intercepting and dampening the effects of rainfall and wind activity. The main purpose for growing vegetation on these sites would be to protect against erosion and off-site transport of soil and or waste material. Plants can also be used to dry out wet areas and help improve aeration. A vegetative cover crop could also be used to help monitor the toxicity of a closed land treatment site.

The selection of suitable plant species to be used on a land treatment site is difficult. There is little data available on the revegetation of these sites. Information on the uptake of hazardous materials by plants is limited at this time to the uptake of metals and to the effects of selected pesticides. Generally speaking, it is important to plant species, subspecies or ecotypes in an environment similar to those on which they occur natively.

Plants which are selected for revegetation purposes should be adapted to the soil and climatic conditions in the area in which they will be used. Any first hand knowledge gained about plants growing in specific geographic areas is helpful. A knowledge of the attributes of plants is helpful to select the most suitable ones for revegetation purposes. Consequently, the experience of others furnishes a good beginning.

All of the plants used in this study were subject to adverse environmental conditions which represent some of the unavoidable risks that occur when conducting field studies of this type. Based upon the results of this study, hardy species which are fairly drought resistant should be used for site revegetation. Despite the fact that adequate water was provided for the plants, many of the trees exhibited signs of dehydration. The red cedar tree which is very drought resistant fared the best. Drought resistant species were better suited to the soil at the study site because of the high temperatures and altered soil-water relations associated with the presence of oil in soil.

Care must be taken when watering vegetation on a land treatment site because once wet, the soil will hold moisture and increase the chances of the soil becoming anaerobic. Soil moisture must be adequate to not only meet the needs of plants, but also to support optimum conditions for the microorganisms degrading the oily waste.

It is critical to monitor the soil nutrients. These nutrients supply the microorganisms as well as plants. In a competition for nutrients between plants and microorganisms, Meyers and Huddleston (1979) concluded that lower nitrogen content in wheat was the result of assimilation by microorganisms degrading the waste oil. The use of nitrogen fixing plants for revegetation purposes may help to alleviate this competition for nitrogen which is often a limiting factor to oil degradation and plant growth.

Grasses are the best choice for initial revegetation of a land treatment site. Grasses provide a quick cover and have root systems which can hold the top layer of soil in place. If grass is to be planted as seed preparations are needed to assure good germination and healthy growth. A layer of composted materials such as manure or possibly treated sewage sludge, should be tilled in with the surface soil and used as a seed bed. This would buffer the vulnerable seeds from the hot soil surface, help retain moisture and cause less injury to seeds from volatile compounds and dissolved constituents during germination and early growth. Our study indicated that approximately a 2.5 cm layer of composted material was beneficial.

Viable seed from native species are often difficult to obtain; therefore, good commercial seed should be used for the revegetation of closed land treatment sites. Grasses may also be planted on a site as sod. If sod is used it should be thick and healthy. Large sod blocks are desirable to limit the edge effects associated with growing sod on this type of soil surface.

The survivability of trees on land treatment sites depends on a number of factors. The most important factors are the concentration of the oil and the depth of penetration of that oil in the soil. Tree growth and development is affected by the amount of available water, nutrients, and toxic constituents in the oily waste.

Until a tree has recovered from the initial shock that planting causes its root system, it should not be exposed to the oil contaminated soil. In order to buffer the roots from the treated soil a large hole about twice the size normally used to plant the tree should be used and filled in with uncontaminated soil. This will give the tree time to establish itself before the roots come in contact with the oily soil.

The grasses which yielded the best growth and appeared to be the most resistant to the presence of oily residues in this study were crabgrass and bermudagrass. The red cedar had the highest survival rate in the test plots followed by russian olive, black locust and osage orange. The grasses and trees selected in general proved to be good choices for the field conditions which were present.

The revegetation of land should be an important part of the site closure procedures for land treatment sites which contain oil refinery waste. A revegetated site is functionally and aesthetically appealing but, until suitable plants which can adapt to the unique environment created by a land treatment system are identified, the revegetation of closed sites remains as much an art as a science.

SECTION 11

DISCUSSION

The current regulations governing land treatment of hazardous wastes were published on Monday, July 26, 1982 in Vol. 47, No. 143 of the Federal Register. A number of the regulations listed were evaluated on the basis of the results of this project.

The treatment zone is defined as the region from the soil surface down to a depth of 1.5 meters (5 feet), with the proviso that the bottom of the zone must be at least 1 meter (3 feet) above the seasonal high water table. The results of this experimental work suggest that this minimum depth above the water table may be too shallow to prevent salts and solubilized metals from reaching the ground water. The lysimeters were installed at a depth of 4 feet and elevated levels of chloride, barium, zinc, iron, manganese, and TOC were found in the soil pore water. In addition, the metal concentrations in the soil below 50 cm at the sites were not statistically higher than background levels. This means that once metals are solubilized, and migrate below the top 50 cm of soil, they remain in solution and migrate with the pore water. Furthermore, it appears that oil which migrates below the aerobic zone (top 20-25 cm), while immobilized, is not degraded and may act as a source of contaminated leachate.

Unpublished work by the authors on land treatment of oily sludges, shows that migration of oil below the till zone is possible even at low (3-5%) loading rates. The exact mechanism by which this migration occurs has not been determined, but the movement of infiltrated water caused by heavy rain may be the driving force. Movement of oil below the till zone is difficult to control even at well managed sites with low loading rates.

Closure requirements include:

(1) The continuation of all operations required to maximize the degradation, transformation or immobilization of hazardous constituents within the treatment zone.
(2) Control of run-off and run-on.
(3) Continuation of unsaturated zone monitoring, except for soil pore liquid monitoring which may be terminated 90 days after the last application of waste to the treatment zone.
(4) The establishment of a vegetative cover, when the cover will not interfere with the continued treatment of the waste.

The results of this research project, support the need for all of the requirements listed. However, it appears that at sites with high loading rates, fulfilling requirement number 1 may take a considerable period of time. In addition, the results suggest that both organic and inorganic pollutants can move through the unsaturated zone in pore water for longer than 90 days after the wastes have been applied. The presence of organics at site 2, six years after closure, even though only in trace amounts, supports the need for extended monitoring of pollutants in the unsaturated zone in pore water as well as soil cores. However, it must be noted that the rate at which oil is applied to the site, and the rate at which it is degraded will determine the length of time for which monitoring the soil pore water must be maintained.

The results of this study suggest that grasses are the best choice for initial revegetation of a land treatment site. Results also indicated that oil concentrations of 4-5% were sufficiently low to allow successful revegetation with grass. However, the growth of grasses was inhibited, and establishing a grass cover undesirable because the rate of further oil degradation would be inhibited, since tilling of the site would have to cease. The authors therefore recommend that revegetation of land treatment sites not be implemented until the degradation rate has decreased to some low constant value.

REFERENCES

Anon, "Landfarming Fills an API Need", Hydrocarbon Processing, Vol. 60, No. 6, June 1980, p. 97.

Archer, S.G. and Bunch, C.E., The American Grass Book, University of Oklahoma Press, Norman, 1953.

Baker, J.M., "The Effects of Oils on Plants", Environmental Pollution, 1970, pp. 27-44.

Black, C.A. et al., Methods of Soil Analyses - Parts 1 and 2, American Society of Agronomy, 1965.

Briggs, L. J. and McCall, A. G., "An Artificial Roof for Inducing Capillary Movement of Soil Moisture", Science, Vol. 30, 1904, pp. 566-569.

Brown, K.W., Brawand, H., Evans, G. and Thomas, J.C., "The Impact of API Separator Sludges on the Emergence and Yield of Ryegrass", R805474010, December, 1979, E.P.A., Texas A & M University.

Carr, R.H., "Vegetative Growth in Soils Containing Crude Petroleum", Soil Science, Vol. 8, 1919, pp. 67-68.

Cresswell, L.W., "Fate of Petroleum in a Soil Environment", EPA/API/UCSG Joint Oil Spill Conference Proceedings, Washington, 1977, pp. 479-482.

Dalrymple, R.L., "Crabgrass as a Forage", No. CG75, Noble Foundation Publication, Ardmore, OK.

Dalrymple, R.L., "Weeping Lovegrass Management", 1976, Noble foundation Bulletin, Ardmore, OK.

Dibble, J.T. and Bartha, R., "Rehabilitation of Oil Inundated Agricultural Land: A Case History", Soil Science, Vol. 128, No. 1, July 1979, pp. 56-60.

Dibble, J.T. and Bartha, R., "Leaching Aspects of Oil Sludge Biodegradation in Soil", Soil Science, Vol. 127, No. 6, June 1979a, p. 365.

Elias, Thomas S., The Complete Trees of North America: Field Guide and Natural History, Van Nostrand Reinhold, New York, 1980.

England, C. B., "Comments on a Technique Using Porous Cups for Water Sampling at Any Depth in the Unsaturated Zone by Warren W. Wood", Water Resources Research, Vol. 10, 1974, p. 1049.

EPA, "Methods for Chemical Analysis of Water and Wastes", EPA-600/4-79-020, March 1979, Environmental Monitoring and Support Laboratory, Environmental Protection Agency, Cincinnati, OH 45268.

EPA, "Development Document for Effluent Limitations Guidelines and Standards for the Petroleum Refining Point Source Category", EPA 440/1-79/014-6, December 1979, Effluent Guidelines Division, Environmental Protection Agency.

EPA, "Test Methods for Evaluating Solid Waste", SW-846 2nd Edition, July 1982, Office of Solid Waste and Emergency Response, Environmental Protection Agency, Washington, D.C. 20460

Federal Register, Vol. 44, No. 233, Monday, December 3, 1979.

Federal Register, Vol. 47, No. 143, Monday, July 26, 1982.

Francsen, C.F., "Landfarming Disposes of Organic Wastes", Pollution Engineering, Vol. 12, No. 2, Feb. 1980, pp. 55-57.

Fuller, W.H., "Movement of Selected Metals, Asbestos and Cyanide in Soil: Applications to Waste Disposal Problems", EPA 660/2-77-020, 1977, Environmental Protection Agency, NTIS PB 266-905.

Giddens, J., "Spent Motor Oil Effects on Soil and Crops", Journal of Environmental Quality, Vol. 5, No. 2, 1976, pp. 179-181.

Gould, Frank W., Common Texas Grasses, Texas A & M Univ. Press, College Station, 1978.

Grove, G.W., "Use Landfarming for Oily Waste Disposal", *Hydrocarbon Process*, Vol. 57, No. 5, May 1978, pp. 138-140.

Grover, B.L. and Lamborn, R.E., "Preparation of Porous Ceramic Cups to be used for Extraction of Soil Water having low Solute Concentrations", *Soil Science Society of America Proceedings*, Vol. 34, 1970, pp. 706-708.

Gudin, C. and Syratt, W.J., "Biological Aspects of Land Rehabilitation Following Hydrocarbon Contaimination", *Environmental Pollution*, 1975, pp. 107-112.

Hahne, H.C.H. and Kroontje, W., "The Simultaneous Effects of pH and Chloride Concentrations upon Mercury as a Pollutant", *Soil Science Society of America Proceedings*, Vol. 37, 1973, pp. 838-843.

Hansen, E. and Harris, A., "Validity of Soil-Water Samples Collected with Porous Ceramic Cups", *Soil Science Society of America Proceedings*, Vol. 39, 1975, pp.528-536.

Hershfield, D.M., "Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years", Technical Report No. 40, May 1961, Weather Bureau, U.S. Department of Commerce.

Huddleston, R.L. and Meyres, J.D., "Treatment of Refinery Oily Wastes by Landfarming", AICHE Symposium Series, Vol. 75, No. 190 Water, 1978.

Huddleston, R.L., "Solid-Waste Disposal: Landfarming", *Chemical Engineering*, Feb. 26, 1979, pp. 119-124.

Huddleston, R.L. et al., "Evaluation of Subsurface Effects of Lone-Term Landfarming", *Land Disposal of Hazardous Waste: Procedings of the 8th Annual Research Symposium, held at Ft. Mitchell, Kentucky on March 8-10, 1982*, Report No. EPA 600/982-002, Mar. 1982, Municipal Environmental Research Lab., Cincinnati, OH.

Hunt, P.G. *et.al.*, "Terrestrial Oil Spills in Alaska: Environmental Effects and Recovery", API/EPA/USCG Conference, Washington, 1973, pp. 733-740.

Johnson, T.M. and Cartwright, K., "Monitoring of Leachate Migration in the Unsaturated Zone in the Vicinity of Sanitary Landfills", Illinois State Geological Survey Bulletin, 1980.

Knowlton, H.E. and Rucker, J.E., "Landfarming Shows", *Oil and Gas Journal*, Vol. 77, No. 20, May 14, 1979, *pp.* 108-110, 115-116.

Leeper, G.W., *Managing the Heavy Metals on the Land*, Marcel Dekker, Inc., New York, 1978.

Levin, M.J. and Jackson, D.R., "A Comparison of in situ Extractors for Sampling Soil Water", *Soil Science Society of America Proceedings*, Vol. 41, 1977, pp. 535-536.

Linkins, A.E., *et.al*., "Impact of Crude Oil on Root Respiration and Levels of Soluable Soil Cellulose in Coastal Arctic Tundra", U.S. Department of Energy Symposium Series, XXX11+911p, April 28-May 1, 1976, pp. 590-604.

Little, Elbert L., *The Audubon Society Field Guide to North American Trees: Western Region*, Alfred A. Knopf. Inc., New York, 1980..

Loehr, R.C., Tewell, W.J., Novak, J.D., Clarkson, W.W. and Freidman, G.S., *Land Application of Wastes*, Vol. 1, Van Nostrand Reinhold, New York, 1979.

McGill, W.B., "An Introduction for Field Personnel to the Effects of Oil Spills on Soil and Some General Restoration and Cleanup Procedures", Alberta Institute of Pedology, A.I.P. Pub. No. G-76-1, July, 1976.

McGill, W.B., and Rowell, M.J., "Determination of Oil Evaluation of Solid Wastes, Volume 1", Final Report, Jan. 1981, United States Environmental Protection Agency, Effluent Guidelines Division, Washington, D.C.

Meyers, J.D. and Huddleston, R.L., "Treatment of Oily Reefinery Wastes by Landfarming", Report Presentation for 34th Annual Purdue Industrial Waste Conference, May 8-10, 1979.

Overcash, M.R. and Pal, D., "Plant-Soil Assimilative Capacity for Oils", *The American Institute of Chemical Engineers*, Vol. 75, No. 190, 1979, pp. 357-361.

Parizek, R. and Lane, B., "Soil Water Sampling Using Pan and Deep Pressure Vacuum Lysimeters", *Journal of Hydrology*, Vol. IX, No. 1, 1970, pp. 1-21.

Phillips, G.R., Gibbs, F.J. and Mattoon, W.R., *Forest Trees of Oklahoma*, 9th ed., Oklahoma State Board of Agriculture, Forestry Division, OK., 1959.

Phillips Petroleum, *Pasture and Range Plants*, Phillips Petroleum Co., Bartlesville, OK., 1963.

Plice, M.J., "Some Effects of Crude Petroleum on Soil Fertility", *Soil Science of America Proceedings*, Vol. 13, 1948, pp. 413-416.

Raymond, R.L., Hudson, J.O., and Jamison, V.W., "Oil Degradation in Soil", *Applied and Environmental Microbiology*, Vol. 31, No. 4, April 1976, pp. 522-535.

Reeve, R.C. and Doering, E.J., "Sampling the Soil Solution for Salinity Appraisal", *Soil Science*, Vol. 39, 1965, pp. 339-344.

Ross, D.E. and Phung, H., "Land Cultivation of Industrial Wastes", SCS Engineers of Long Beach, California, 1977, pp. 366-376.

Schilesky, D.M., "Land Cultivation of Industrial Sludges: Site Selection and Design Criteria", *Sludge*, Vol. 2, No. 3, May-June 1979, p. 26.

Schwedinger, R.B., "Reclamation of Soil Contaminated by Oil", *Journal of the Institute of Petroleum*, Vol. 54, No. 535, 1968, pp. 182-197.

Smith, R.A.H. and Bradshaw, A.D., "The Use of Metal Tolerant Plant Populations for the Reclamation of Metalliferous Wastes", *Journal of Applied Ecology*, Vol. 16, 1979, pp. 595-612.

Thames, J.E. ed., *Reclamation and Use of Distrubed Land in the Southwest*, Univ. Arizona Press, Arizona, 1977.

Van der Ploeg, R. and Beese, F., "Model Calculations for the Extraction of Soil Water by Ceramic Cups and Plates", Soil Science Society of America Journal, Vol. 41, 1977, pp. 466-472.

Vasey, George, Illustrations of North American Grasses, Vol. II, U.S. Department of Agriculture, Washington, 1893.

Wagner, G.H., "Use of Porous Ceramic Cups to Sample Soil Water Within the Profile", Soil Science, Vol. 94, 1962, pp. 379-386.

Watts, J.R. and Corey, J.C., "Land Application Studies of Industrial Waste Oils and Solvents, D.E.-AC09-SR00001, U.S. Department of Energy, 1981.

Wood, W.W., "A Technique Using Porous Cups for Water Sampling at any Depth in the Unsaturated Zone", Water Resources Research, Vol. 9, No. 2, 1973, pp. 486-488.

Zimmerman, C.F., Price, M.T. and Montgomery, J.R., "A Comparison of Ceramic and Teflon in situ Samplers for Nutrient Pore Water Determinations", Estuarine and Coastal Marine Science, Vol. 7, 1978, pp. 93-97.

APPENDIX A
ANALYTICAL METHODS

Oil Content

Two procedures were used for oil content determinations. The oil content of the sludges and soil sludge mixtures was determined by extraction with dichloromethane, using the procedure of McGill and Rowell (1980). In this procedure, 10 grams of the sample were extracted for 4 hours using a Soxhlet extraction apparatus. Prior to extraction, the soil was ground so that it could pass through a 40 mesh sieve, and then quartered to obtain the desired sample size. The extract was then evaporated down to a volume of 15 to 20 ml on a steam bath, transferred to a preweighed aluminum dish, and allowed to air dry in a fume hood overnight. The sample was then purged with nitrogen gas, by directing a steam at the gas onto the surface of the residue in the aluminum dish. The purging was necessary to drive off any remaining dichloromethane. The residue and aluminum dish were then weighed, and the weight of oil determined. The thimbles plus soil were oven dried at 103°C, and the weight of dry soil obtained. The oil content was then expressed as a dry weight.

The oil content of the aqueous samples was determined gravimetrically, using method 413.1 from test "Methods for Chemical Analysis of Water and Wastes" published by the Environmental Protection Agency (March 1979).

Fractionation Analysis of Oil

Fractionation analysis on the oil extracts from the site soils was carried out using ASTM Method D-2007-73. Initial analyses were performed on standard oils obtained from the Agronomy Department at Texas A & M University, to verify the method.

Metal Analysis

Heavy metal analyses were carried out on sludges, site soil, and soil pore water. The sludges and site soil samples were analyzed using a digestion procedure obtained from the Environmental Protection Agency's Robert S. Kerr Environmental Research Laboratory (RSKERL) in Ada, Oklahoma. In this procedure, between 0.2 and 1 gram of sample was accurately weighed in an acid-washed beaker, 10 mls of concentrated nitric acid added to the beaker, and the mixture just evaporated to dryness. 10 more mls of acid were then added to the beaker, and the beaker was covered and allowed to reflux gently for a minimum of 2 hours. When ashing of the sample was complete, indicated by the absence of vigorous reaction, the beaker was cooled, 1 ml of 30% H_2O_2 added and the digestion was continued. Additional 1 ml portions of H_2O_2 were added up to a maximum of 10 mls, until ashing was complete. This stage was denoted by no further changes in the color of the sample. The cover was then removed from the beaker, and the sample evaporated until just dry. 3 mls of nitric acid were then added, the beaker heated to solubilize the residue, and then 25 mls of water were added. The beaker was then covered, and the contents allowed to digest for 1 hour. The sample was then transferred to a 100 ml volumetric flask, diluted to volume, and analyzed by AA.

The aqueous samples were prepared for analysis using methods 3010 or 3020 from "Test Methods for Evaluating Solid Waste-Physical/Chemical Methods" published by the Environmental Protection Agency.

All samples were analyzed on a IL Model 551 Atomic Absorption Spectrophotometer, equipped with a Model 655 furnace.

Chloride Analysis

The method used for chloride analysis of soils was taken from "Methods of Soil Analysis" published by the American Agronomy Society (Black et al., 1979). Both 1:5 and 1:1 ratios of soil to water were used. The chloride ion concentration in the soil spore water samples was determined using method 325.3 - titritmetric determination with mercuric nitrate - taken from the EPA manual Methods for Chemical Analysis of water and wastes.

pH Determination

The pH determination for soils was done according to the procedure outlined in Methods of Soil Analysis (Black et al., 1979).

The soil sample was diluted 1:1 with water and mixed for 30 minutes. The mixture was allowed to stand for one hour to settle, and then the pH was determined using an Orion Model 401 pH meter.

Nitrate

Soil nitrate determinations were carried out using the phenoldisulfonic acid method described in part 2 of Methods of Soil Analysis published by the American Agronomy Society (Black et al., 1965). This procedure involves the development of a yellow color with phenoldisulfonic acid by the nitrate ion in an aqueous extract of the soil.

Available Phosphorus - Bray's Method

The method used, determined the phosphorus in the soil soluble in NH_4F/HCl solution. The procedure used was taken from Methods of Soil Analysis, edited by Black et al.

Total Organic Carbon

The total organic carbon content of aqueous samples was determined using a Beckmann Model 915 Total Organic

Carbon Analyzer with an infra red detector. The total organic carbon content of the soil samples was determined in two ways. The first set of determinations were carried out using the Walkley-Black Method with external heat as described in Methods of Soil Analysis edited by Black et al. In this method, the carbon is oxidized with potassium dichromate at a temperature of 150°C. Later determinations were performed on a Leco Total Organic Carbon Analyzer.

Priority Pollutant Analysis

The soil samples were extracted for priority pollutant analysis by using a combination of Methods 3540 and 3530 in the EPA Manual Test Methods for evaluating solid waste. In the first part of the procedure, the solid sample was subjected to Soxhlet extraction using dichloromethane, as described in Method 3540. The extract from this procedure was concentrated to about 2.5 mls, and 0.5 mls removed for analysis for volatiles. The remainder was then extracted by Method 3530, yielding a base/neutral and phenolics fraction. The three fractions were then analyzed by GC/MS. The instrument used was a Hewlett-Packard Model 5985B GC/MS. The GC was fitted with a DB-5 30 meter, fused silica, capillary column.

Cation Exchange Capacity

The cation exchange capacity of the soil at each site was determined using the ammonium saturation method. This procedure was taken from "Methods of Soil Analysis" edited by Black *et al.* The procedure entailed saturation of the air-dried soil with neutral 1N NH_4OAC, followed by removal of the absorbed NH_4^+ by passing air through a suspension of the NH_4^+ saturated soil in Na_2CO_3 solution. The displaced NH_4^+ ions were then passed into a container with H_2SO_4. By determining how much acid reacted with the NH_4^+ ion, the concentration of NH_4^+ ion could be determined, and hence the cation exchange capacity of the soil.

APPENDIX B

SITE SOIL DATA

TABLE B-1. TOTAL ORGANIC CARBON

Site 1

Location	TOC %
	11/10/81
Bkg T	2.0
Bkg B	1.3
1T	10.0
1B	0.9
2T	10.2
2B	2.1
3T	13.4
5T	13.6
6T	4.9

Site 2

Location	TOC. %	
	7/21/81	11/12/81
Bkg T	1.1	0.8
Bkg B	0.5	0.3
1T	4.2	4.8
1B	3.9	0.1
2T	4.1	4.0
2B	1.3	0.2
3T	4.1	5.3
3B	1.8	0.3
4T	6.7	5.5
4B	7.2	1.3
5T	1.7	6.9
5B	1.0	1.9
6T	0.7	4.6
6B	0.6	1.3

(continued)

TABLE B-1. (continued)

Site 3

Location	TOC. %
	11/17/81
Bkg T	1.4
Bkg B	0.3
1T	7.6
1B	1.4
2T	1.7
2B	1.1
3T	14.6
3B	8.8
4T	13.6
4B	11.7
5T	18.4
5B	10.7

TABLE B-2. CHLORIDE ION CONCENTRATION (mg/kg)

Site 1

Date	Location	Concentration (mg/kg) (1:5 ratio)*	(1:1 ratio)*
6/30/82	Bkg T	17.6	5.5
	Bkg B	15.4	-
	1T	167.0	-
	1B	136.1	103.9
	2T	161.5	-
	2B	112.1	93.5
	3T	68.1	-
	3B	70.4	58.0
	4T	108.8	-
	4B	87.4	85.7
	5T	106.6	-
	5B	130.5	109.9
	6T	105.5	-
	6B	83.5	69.8

* Ratio of soil to water

Site 2

Date	Location	Concentration (mg/kg) (1:1 ratio)*	(1:5 ratio)*
7/8/82	Bkg T	13.7	47.8
	Bkg B	2.9	17.6
	1TU	24.9	52.7
	1BU	28.1	-
	2TU	24.9	19.8
	2BU	45.1	-
	3TU	19.0	22.8
	3BU	-	-
	4TU	28.2	33.9
	4BU	23.9	-
	5TU	34.3	37.5
	5BU	35.4	-
	6TU	36.9	24.2
	6BU	-	-

* Ratio of soil to water

TABLE B-2. (continued)

Site 3

Date	Location	Concentration (mg/kg) (1:5 ratio)*	(1:1 ratio)*
11/4/82	Bkg T	19.8	15.4
	Bkg B	7.3	4.1
	2T	48.5	17.2
	4T	125.1	99.6
	4B	150.4	141.7
	5T	71.7	51.1
	5B	52.5	49.2
	6T	44.9	52.1

* Ratio of soil to water

TABLE B-3. SOIL pH

Site 1

Location	pH	
	11/10/81	12/1/82
Bkg T	-	7.4
Bkg B	-	7.5
1T	7.2	7.1
1B	-	7.5
2T	7.6	7.0
2B	-	7.5
3T	7.4	7.2
3B	-	7.3
4T	-	7.1
4B	-	7.3
5T	7.2	7.0
5B	-	7.5
6T	7.5	7.1
6B	-	7.2

Site 2

Location	pH		
	7/21/81	11/12/81	11/19/82
Bkg T	6.8	7.0	7.2
Bkg B	6.8	-	7.8
1T	6.9	7.0	7.0
1B	7.9	-	7.2
2T	6.2	7.1	7.4
2B	5.8	-	7.3
3T	6.2	7.3	7.3
3B	5.8	-	7.6
4T	6.7	7.3	7.3
4B	7.3	-	7.4
5T	6.1	7.2	7.2
5B	6.2	-	6.8
6T	6.4	7.4	7.1
6B	6.3	-	7.2

(continued)

TABLE B-3. (continued)

Site 3

Location	pH		
	7/16/81	11/17/81	3/26/82
Bkg T	5.8	7.2	-
1T	7.5	7.4	7.7
1B	7.2	-	-
2T	7.4	7.4	7.1
2B	6.6	-	-
3T	7.2	-	7.5
3B	6.8	-	-
4T	7.6	7.3	7.3
4B	6.0	-	-
5T	7.3	7.4	7.6
5B	7.3	-	-
6T	-	-	7.6
6B	-	-	-

TABLE B-4. OIL CONTENT DATA %

Site 1	Location	Date							
		9/3/81	11/10/81	4/8/82	6/14/82	6/30/82	8/4/82	12/1/82	1/18/83
	BGT	0.8	0.1	0.3	0.5	-	-	0.5	1.0
	1TU	2.3	2.5	4.4	6.6	-	-	6.9	5.9
	1BU	3.8	0.1	0.7	1.9	0.7	-	1.5	-
	2TU	-	1.7	7.1	-	-	5.8	7.7	8.2
	2BU	-	0.1	0.8	-	8.0	1.0	1.2	-
	3TU	1.5	1.2	3.4	2.5	3.6	2.3	2.9	-
	3BU	1.0	0.3	-	0.1	0.3	0.2	0.6	-
	4TT	2.5	-	4.0	-	5.5	-	4.7	-
	4BT	0.1	-	0.4	-	0.1	-	0.7	-
	5TT	3.4	1.2	6.5	8.0	-	7.1	8.3	7.9
	5BT	-	-	1.1	-	-	1.5	3.0	-
	6TT	3.1	1.2	4.0	4.0	6.2	-	3.2	5.8
	6BT	0.2	0.4	0.2	0.1	0.1	-	4.1	-
	BGB	-	0.0	0.1	0.1	-	-	0.2	-

(continued)

TABLE B-4. (continued)

Site 2	Location	Date					
		11/12/81	4/6/82	7/8/82	11/19/82	6/16/82	2/16/83
	BGT	0.0	0.3	3.7	0.4	3.1	0.6
	BGB	0.0	0.1	0.5	0.4	0.3	-
	1TT	1.7	2.8	2.4	3.3	-	3.0
	1BT	0.3	1.4	1.1	-	-	-
	1TU	0.8	3.8	3.1	3.1	-	-
	1BU	0.2	-	1.6	1.0	-	-
	2TT	-	2.5	3.0	2.1	-	2.6
	2BT	-	0.5	1.5	1.3	-	-
	2TU	1.5	2.5	4.8	0.1	-	-
	2BU	0.3	-	1.0	0.1	-	-
	3TT	-	1.6	1.7	1.8	.5	1.7
	3BT	0.2	0.6	0.6	0.1	0.1	-
	3TU	1.4	3.3	2.9	1.1	-	-
	3BU	0.1	-	1.9	0.2	-	-
	4TT	0.2	1.7	1.8	1.2	-	0.7
	4BT	0.0	0.4	1.0	0.3	-	-
	4TU	1.9	2.8	0.4	3.7	-	-
	4BU	0.3	0.5	1.1	2.8	-	-
	5TT	-	4.2	4.0	4.7	-	5.1
	5BT	-	1.0	1.2	3.0	-	-
	5TU	1.0	2.9	3.7	3.6	-	-
	5BU	0.4	-	1.2	2.1	-	-
	6TT	-	3.0	-	4.5	0.2	4.7
	6BT	-	0.8	-	2.6	0.1	1.7
	6TU	1.0	2.4	0.7	4.3	1.3	-
	6BU	0.2	0.5	0.2	0.3	0.2	-

(continued)

TABLE B-4. (continued)

Site 3	Location	Date						
		11/17/81	3/26/82	7/29/82	10/19/82	11/4/82	3/8/83	6/7/83
	BGT	0.2	0.1	-	0.5	-	1.1	2.3
	BGB	0.1	0.1	-	0.1	-	-	0.1
	1T	3.0	5.3	-	-	-	-	4.0
	1B	-	0.1	-	-	-	-	0.5
	2T	2.0	5.6	-	5.2	-	-	5.7
	2B	0.9	0.2	-	-	-	-	0.9
	3T	8.6	10.5	-	-	-	11.0	9.3
	3B	3.5	0.2	-	-	-	-	1.4
	4T	4.9	8.4	13.2	13.9	-	15.3	14.1
	4B	6.1	2.3	2.4	17.9	-	-	8.6
	5TT	4.6	9.6	17.3	13.1	13.4	20.8	15.6
	5BT	2.4	10.7	6.2	5.9	-	-	9.9
	6T	-	12.8	12.5	-	11.9	12.0	9.4
	6B	-	-	8.7	-	-	-	9.5

TABLE B-5 SOIL METALS DATA

SITE 1

SITECODE	ID	BA	SE	AS	CU	CD	CO	NI	PB	ZN	AL	CR	AG	MN	FE
10702915	1(0-6)	.	.	.	183.00	<1.00	22.00	314.00	97.00	323.00	17790.00	126.00	15.00	.	.
	1(6-12)	.	.	.	129.00	<1.00	.	29.00	65.00	243.00	.	88.00	.	.	.
	2(0-6)	.	.	.	274.00	1.00	.	42.00	151.00	514.00	.	263.00	.	.	.
	2(6-9)	.	.	.	141.00	<1.00	23.00	75.00	83.00	176.00	29300.00	107.00	13.00	.	.
	3(0-8)	.	.	.	246.00	<1.00	.	43.00	291.00	554.00	.	232.00	.	.	.
	4(0-8)	.	.	.	256.00	<1.00	22.00	137.00	93.00	586.00	21380.00	317.00	24.00	.	.
	4(7-12)	.	.	.	18.00	<1.00	16.00	75.00	10.00	56.00	31650.00	7.00	2.00	.	.
	5(0-10)	.	.	.	316.00	<1.00	28.00	82.00	137.00	583.00	20213.00	350.00	30.00	.	.
	6(0-8)	.	.	.	246.00	1.00	.	37.00	95.00	660.00	.	360.00	.	.	.

(continued)

Reproduced from best available copy.

TABLE B-5 (continued)

SITE 1

```
SITECODE     ID                    BA          SE           AS

10702815     BGD(0-6)              .           .            .
             BGB                   .           .        340.00

                      CU           CD          CU           NI

                   18.00        <1.00       16.00       117.00
                   11.00         4.00        7.00        19.00

                      PB           ZN          AL           CR

                   23.00        10.00           .            .
                   27.00        20.00    20600.00        37.00

                      AG           MN          FE

                    4.00            .           .
                    1.00            .           .
```

(continued)

Reproduced from
best available copy.

TABLE B-5 (continued)

SITE 1

SITECODE	ID	BA	SE	AS	CU	CD	CO	NI	PB	ZN	AL	CR	AG	MN	FE
11110815	1B	.	.	400.00	19.00	1.00	7.00	23.00	43.00	46.00	23160.00	53.00	2.00	.	.
	1B	.	.	270.00	21.00	4.00	13.00	20.00	43.00	61.00	18660.00	<1.00	3.00	.	.
	1T	.	.	440.00	180.00	<1.00	7.00	44.00	137.00	489.00	16710.00	270.00	17.00	.	.
	2B	.	.	340.00	32.00	4.00	10.00	27.00	33.00	73.00	24220.00	57.00	5.00	.	.
	2B	.	.	370.00	33.00	1.00	7.00	35.00	47.00	65.00	25140.00	<1.00	5.00	.	.
	2T	.	.	270.00	143.00	4.00	17.00	231.00	93.00	274.00	18230.00	110.00	17.00	.	.
	3T	.	.	340.00	154.00	4.00	7.00	57.00	100.00	272.00	12880.00	157.00	14.00	.	.
	5T	.	.	400.00	187.00	1.00	10.00	44.00	123.00	443.00	13170.00	140.00	17.00	.	.
	6T	.	.	270.00	56.00	5.00	7.00	28.00	57.00	195.00	18840.00	90.00	6.00	.	.

(continued)

Reproduced from best available copy.

TABLE B-5 (continued)

SITE 1

SITECODE	ID	BA	SE	AS	CU	CD	CO	NI	PB	ZN	AL	CR	AG	MN	FE
10614825	BGT	96.00	.	.	13.00	<1.00	.	13.00	30.00	121.00	.	30.00	3.00	.	.
	BGB	94.00	.	.	9.00	<1.00	.	16.00	17.00	64.00	.	33.00	3.00	.	.
	1T	41.00	.	.	202.00	<1.00	.	23.00	112.00	523.00	.	248.00	17.00	.	.
	1B	101.00	.	.	76.00	<1.00	.	15.00	56.00	307.00	.	141.00	4.00	.	.
	3T	174.00	.	.	64.00	<1.00	.	28.00	75.00	207.00	.	70.00	3.00	.	.
	3B	94.00	.	.	13.00	<1.00	.	24.00	20.00	191.00	.	38.00	3.00	.	.
	6T	122.00	.	.	140.00	<1.00	.	32.00	79.00	431.00	.	337.00	7.00	.	.
	6B	86.00	.	.	14.00	.	.	17.00	10.00	64.00	.	45.00	3.00	.	.
	1T	630.00	.	.	215.00	<1.00	.	31.00	120.00	758.00	.	263.00	18.00	.	.

(continued)

Reproduced from
best available copy.

TABLE B-5 (continued)

SITE 2

SITECODE	ID	BA	SE	AS	CU	CD	CO	NI	PB	ZN	AL	CR	AG	MN	FE
20721815	1(0-6)	.	.	.	76.00	<1.00	22.70	60.00	113.00	208.00	23140.00	270.00	7.00	.	.
	1(6-12)	.	.	.	17.70	<1.00	21.00	38.00	50.00	65.00	20700.00	127.00	5.00	.	.
	1(12+)	.	.	.	23.30	<1.00	27.00	46.00	23.00	19.00	11650.00	73.00	3.00	.	.
	2(0-8)	.	.	.	59.70	1.30	24.70	56.00	53.00	89.00	34370.00	140.00	0.00	.	.
	2(8+)	.	.	.	33.00	<1.00	30.70	84.00	33.00	67.00	42330.00	137.00	6.00	.	.
	3(0-8)	.	.	.	283.00	<1.00	25.70	44.00	47.00	74.00	25270.00	77.00	4.00	.	.
	3(8+)	.	.	.	23.30	<1.00	26.70	54.00	27.00	44.00	29850.00	87.00	4.00	.	.
	4(0-8)	.	.	.	88.70	<1.00	23.70	57.00	197.00	377.00	30000.00	460.00	10.00	.	.
	4(8-16)	.	.	.	23.70	<1.00	24.30	56.00	133.00	160.00	28390.00	223.00	7.00	.	.

(continued)

Reproduced from
best available copy.

TABLE B-5 (continued)

SITE 2

SITECODE	ID	BA	SE	AS
20721815	5(0-8)	.	.	.
	5(8+)	.	.	.
	6(0-8)	.	.	.
	6(8+)	.	.	.
	BGT	.	.	.
	dGB	.	.	.

CU	CD	CO	NI
22.30	<1.00	29.70	76.00
11.70	<1.00	29.30	104.00
15.00	<1.00	21.00	29.00
18.70	<1.00	22.30	41.00
18.30	<1.00	14.00	35.00
14.00	<1.00	17.00	50.00

PB	ZN	AL	CR
50.00	70.00	25210.00	73.00
20.00	22.00	30970.00	70.00
13.00	<0.10	14000.00	53.00
23.00	9.00	16710.00	73.00
20.00	19.00	13780.00	27.00
17.00	12.00	13990.00	43.00

AG	MN	FE
5.00	.	.
3.00	.	.
1.00	.	.
5.00	.	.
4.00	.	.
3.00	.	.

(continued)

Reproduced from
best available copy.

TABLE B-5 (continued)

SITE 2

SITECODE	ID	BA	SE	AS	CU	CD	CO	NI	PB	ZN	AL	CR	AG	MN	FE
21112815	1DT	.	.	33.00	10.00	<1.00	10.00	27.00	30.00	43.00	12420.00	3.00	2.00	.	.
	1TT	.	.	<0.01	24.00	<1.00	<3.00	12.00	77.00	141.00	10500.00	93.00	4.00	.	.
	1BU	.	.	<0.01	14.00	<1.00	7.00	42.00	17.00	45.00	16230.00	20.00	<0.20	.	.
	1TU	.	.	<0.01	38.00	<1.00	10.00	29.00	113.00	175.00	13000.00	167.00	5.00	.	.
	1BT	.	.	<0.01	11.00	<1.00	7.00	26.00	37.00	42.00	16490.00	<1.00	3.00	.	.
	2TU	.	.	<0.01	22.00	<1.00	3.00	45.00	47.00	167.00	8700.00	67.00	3.00	.	.
	2BU	.	.	67.00	9.00	<1.00	10.00	20.00	10.00	49.00	16460.00	<1.00	<0.20	.	.
	3BU	.	.	67.00	8.00	<1.00	10.00	15.00	20.00	33.00	10100.00	<1.00	2.00	.	.
	3TU	.	.	<0.01	35.00	<1.00	7.00	21.00	97.00	130.00	11440.00	193.00	3.00	.	.

(continued)

Reproduced from best available copy.

TABLE B-5 (continued)

SITE 2

SITECODE	ID	BA	SE	AS	CU	CD	CO	NI	PB	ZN	AL	CR	AG	MN	FE
21112815	4BT	.	.	<0.01	11.00	3.00	7.00	128.00	27.00	84.00	11850.00	17.00	1.00	.	.
	4TT	.	.	67.00	21.00	<1.00	7.00	58.00	47.00	94.00	10670.00	70.00	6.00	.	.
	4TT	.	.	<0.01	22.00	<1.00	3.00	84.00	60.00	106.00	11120.00	60.00	3.00	.	.
	4BU	.	.	<0.01	13.00	2.00	7.00	28.00	23.00	52.00	17770.00	50.00	16.00	.	.
	4TU	.	.	<0.01	44.00	<1.00	7.00	27.00	120.00	188.00	10960.00	157.00	4.00	.	.
	5BU	.	.	<0.01	15.00	<1.00	10.00	17.00	27.00	41.00	21400.00	27.00	3.00	.	.
	5TU	.	.	<0.01	32.00	<1.00	7.00	19.00	70.00	166.00	13350.00	170.00	4.00	.	.
	8GB	.	.	<0.01	6.00	<1.00	3.00	11.00	13.00	31.00	9410.00	<1.00	1.00	.	.
	8GT	.	.	<0.01	6.00	<1.00	<0.20	8.00	17.00	26.00	6360.00	<1.0	1.00	.	.

(continued)

Reproduced from best available copy.

TABLE B-5 (continued)

SITE 2

SITECODE	ID	BA	SE	AS
2111281S	8GB	.	.	<0.01
	BGT	.	.	<0.01
	8BU	.	.	<0.01
	6TU	.	.	<0.01

CU	CD	CO	NI
21.00	<1.00	7.00	23.00
9.00	<1.00	7.00	11.00
14.00	1.00	7.00	22.00
33.00	<1.00	13.00	20.00

PB	ZN	AL	CR
13.00	50.00	10940.00	20.00
23.00	41.00	8610.00	33.00
30.00	59.00	19860.00	43.00
113.00	162.00	17060.00	137.00

AG	MN	FE
<3.00	.	.
<3.00	.	.
4.00	.	.
<3.00	.	.

(continued)

Reproduced from best available copy.

TABLE B-5 (continued)

SITE 2

SITECODE	ID	BA	SE	AS	CU	CD	CD	NI	PB	ZN	AL	CR	AG	MN	FE
20616825	8GT	5.00	.	.	7.00	<1.00	.	8.00	16.00	68.00	.	18.00	<3.00	.	.
	8GB	3.50	.	.	4.00	<1.00	.	22.00	10.00	67.00	.	17.00	<3.00	.	.
	3T	8.00	.	.	9.00	<1.00	.	8.00	11.00	52.00	.	40.00	<3.00	.	.
	3B	6.00	.	.	6.00	<1.00	.	11.00	11.00	34.00	.	27.00	<3.00	.	.
	6TU	10.00	.	.	30.00	<1.00	.	12.00	60.00	160.00	.	152.00	<3.00	.	.
	6BU	8.00	.	.	10.00	<1.00	.	10.00	11.00	69.00	.	36.00	<3.00	.	.
	6TT	18.50	.	.	13.00	<1.00	.	7.00	30.00	99.00	.	86.00	<3.00	.	.
	6BT	13.50	.	.	13.00	<1.00	.	16.00	8.00	151.00	.	37.00	<3.00	.	.
	3T	9.00	.	.	10.00	<1.00	.	13.00	15.00	96.00	.	33.00	<3.00	.	.

(continued)

Reproduced from best available copy.

TABLE B-5 (continued)

SITE 3

SITECODE	ID	BA	SE	AS	CU	CD	CO	NI	PB	ZN	AL	CR	AG	MN	FE
31117815	1B	.	.	333.00	15.00	<1.00	10.00	16.00	33.00	<0.10	15800.00	43.00	4.00	.	.
	1B	.	.	267.00	18.00	<1.00	10.00	18.00	47.00	<0.10	14900.00	53.00	4.00	.	.
	1T	.	.	<0.01	28.00	<1.00	13.00	22.00	64.00	35.00	18400.00	110.00	4.00	.	.
	2B	.	.	133.00	11.00	<1.00	13.00	18.00	40.00	66.00	18850.00	60.00	2.00	.	.
	2T	.	.	167.00	8.00	<1.00	7.00	19.00	20.00	<0.10	18820.00	40.00	3.00	.	.
	3B	.	.	<0.01	32.00	<1.00	3.00	40.00	70.00	32.00	22550.00	67.00	6.00	.	.
	3T	.	.	33.00	53.00	<1.00	10.00	199.00	117.00	174.00	22220.00	97.00	7.00	.	.
	4B	.	.	100.00	58.00	<1.00	<1.00	24.00	130.00	97.00	24200.00	23.00	8.00	.	.
	4T	.	.	67.00	44.00		10.00	17.00	93.00	62.00	28030.00	23.00	6.00	.	.

(continued)

Reproduced from best available copy.

TABLE B-5 (continued)

SITE 3

```
SITECODE    ID                    BA           SE           AS

31117815    SB                     .            .        <0.01
            ST                     .            .       167.00
            BGB                    .            .        <0.01
            BGT                    .            .        <0.01
                       CU         CD           CO           NI

                    29.00      <1.00        10.00        48.00
                    58.00      <1.00         3.00        40.00
                     8.00      <1.00        13.00        16.00
                    15.00      <1.00         7.00        40.00
                       PB         ZN           AL           CR

                    70.00      65.00     23960.00        50.00
                   160.00      86.00     22910.00        63.00
                    23.00      <0.10     13500.00        30.00
                    30.00       5.00     17810.00        20.00
                        AG         MN           FE

                      3.00        .            .
                      9.00        .            .
                      2.00        .            .
                      4.00        .            .
```

(continued)

Reproduced from
best available copy.

TABLE B-5 (continued)

SITE 3

SITECODE	ID	BA	SE	AS	CU	CD	CU	NI	PB	ZN	AL	CR	AG	MN	FE
3062V825	1T	59.00	.	.	10.00	<1.00	.	8.00	13.00	59.00	.	36.00	<3.00	.	.
	1B	67.00	.	.	10.00	<1.00	.	18.00	13.00	67.00	.	44.00	<3.00	.	.
	4T	133.00	.	.	43.00	<1.00	.	12.00	87.00	133.00	.	67.00	<3.00	.	.
	4B	56.00	.	.	15.00	<1.00	.	22.00	30.00	56.00	.	71.00	<3.00	.	.
	2T	89.00	.	.	16.00	<1.00	.	19.00	23.00	89.00	.	48.00	<3.00	.	.
	2B	121.00	.	.	6.00	<1.00	.	21.00	20.00	121.00	.	33.00	<3.00	.	.
	3T	213.00	.	.	30.00	<1.00	.	16.00	96.00	213.00	.	68.00	<3.00	.	.
	3B	42.00	.	.	12.00	<1.00	.	28.00	15.00	42.00	.	37.00	<3.00	.	.
	4T	214.00	.	.	43.00	<1.00	.	20.00	60.00	214.00	.	60.00	<3.00	.	.
														.	.

(continued)

Reproduced from
best available copy.

TABLE B-6 DEEP CORES METALS DATA

SITE 1

SITECODE	ID	BA	SE	AS	CU	CD	CO	NI	PB	ZN	AL	CR	AG	MN	FE
11230815	2(45-50)	.	.	.	14.00	<1.00	.	38.00	13.00	40.00	33830.00	.	5.00	.	.
	2(50-60)	.	.	.	6.00	<1.00	.	27.00	20.00	43.00	29170.00	.	1.00	.	.
	3(32-48)	.	.	.	3.00	<1.00	.	27.00	13.00	40.00	31170.00	.	2.00	.	.
	3(32-48)	.	.	.	8.00	<1.00	.	36.00	23.00	37.00	32000.00	.	1.00	.	.
	6(32-41)	.	.	.	9.00	<1.00	.	44.00	20.00	30.00	27670.00	.	4.00	.	.
	6(45-50)	.	.	.	24.00	<1.00	.	40.00	17.00	50.00	27500.00	.	7.00	.	.
	BGD(30-42)	123.00	.	.	8.00	3.00	.	22.00	18.00	44.00	.	26.00	3.00	.	.
	BGD(50-62)	58.00	.	.	14.00	3.00	.	11.00	17.00	46.00	.	29.00	4.00	.	.

(continued)

Reproduced from best available copy.

TABLE B-6 (continued)

SITE 1

SITECODE	ID	BA	SE	AS	CU	CD	CO	NI	PB	ZN	AL	CR	AG	MN	FE
10630825	BGD(30-42)	125.00	.	.	8.00	<3.00	.	22.00	18.00	44.00	.	26.00	<3.00	.	.
	BGD(56-62)	58.00	.	.	14.00	<3.00	.	11.00	17.00	46.00	.	29.00	4.00	.	.
	1(34-36)	250.00	.	.	9.00	<3.00	.	16.00	20.00	46.00	.	23.00	<3.00	.	.
	1(50-55)	54.00	.	.	9.00	<3.00	.	33.00	6.00	51.00	.	60.00	5.00	.	.
	6(30-35)	63.00	.	.	9.00	<3.00	.	17.00	36.00	49.00	.	30.00	<3.00	.	.
	6(49-55)	43.00	.	.	9.00	<3.00	.	11.00	10.00	65.00	.	26.00	<3.00	.	.
	1(34-36)	165.00	.	.	9.00	<3.00	.	7.00	29.00	38.00	.	22.00	<3.00	.	.

(continued)

Reproduced from
best available copy.

TABLE B-6 (continued)

SITE 2

```
SITECODE   ID                 BA          SE          AS

2122181    3(26-30)            .           .           .
           3(30-36)            .           .           .
           3(36-40)            .           .           .
           5(26-36)            .           .           .
           5(36-49)            .           .           .
           5(49-60)            .           .           .
           6(26-32)            .           .           .
           6(32-49)            .           .           .
           6(49-58)            .           .           .
                    CU          CD          CO          NI

                 18.00
                              3.00           .       24.00
                  6.00       <3.00           .       25.00
                  5.00        3.00           .        9.00
                 14.00       <3.00           .       61.00
                 15.00        3.00           .       19.00
                 21.00       <3.00           .       76.00
                 16.00       <3.00           .       17.00
                 14.00       <3.00           .       35.00
                 21.00       <3.00           .       35.00
                                             .
                    PB          ZN          AL          CR

                 20.00       33.00    13330.00           .
                 17.00        1.00     8670.00           .
                 17.00       17.00     7030.00           .
                 20.00       43.00    18500.00           .
                 30.00       33.00    13670.00           .
                 80.00       80.00    17670.00           .
                 <2.00       67.00    11000.00           .
                 13.00       20.00     6670.00           .
                  3.00       33.00    21000.00           .
                                                         .
                    AG          MN          FE

                  2.00           .           .
                  1.00           .           .
                  3.00           .           .
                  1.00           .           .
                  1.00           .           .
                  2.00           .           .
                  3.00           .           .
                 <1.00           .           .
                  5.00           .           .
                                 .           .
```

(continued)

Reproduced from best available copy.

TABLE B-6 (continued)

SITE 2

SITECODE	ID	BA	SE	AS
20708823	BGD(30-42)	102.00	•	•
	BGD(56-62)	75.00	•	•
	2(33-37)	16.00	•	•
	2(51-60)	37.00	•	•
	4(34-40)	112.00	•	•
	4(50-54)	12.00	•	•
	6(34-38)	16.00	•	•
	6(50-58)	30.00	•	•
	2(33-37)	83.00	•	•

CU	CD	CO	NI
6.00	<3.00	•	22.00
3.00	6.00	•	8.00
3.00	<3.00	•	14.00
9.00	4.00	•	9.00
9.00	<3.00	•	7.00
3.00	<3.00	•	4.00
3.00	<3.00	•	15.00
3.00	<3.00	•	2.00
6.00	<3.00	•	7.00

PB	ZN	AL	CR
18.00	33.00	•	18.00
7.00	16.00	•	10.00
13.00	23.00	•	13.00
9.00	26.00	•	22.00
7.00	25.00	•	19.00
6.00	15.00	•	9.00
5.00	19.00	•	16.00
7.00	4.00	•	4.00
6.00	19.00	•	16.00

AG	MN	FE
<3.00	•	•
<3.00	•	•
<3.00	•	•
<3.00	•	•
<3.00	•	•
<3.00	•	•
<3.00	•	•
<3.00	•	•
<3.00	•	•

(continued)

Reproduced from best available copy.

TABLE B-6 (continued)

SITE 2

```
SITECODE    ID                    BA          SE          AS

2122181     B(49-58)              .            .           .
            BGD(30-35)        102.00           .           .
            BGD(56-62)         75.00           .           .

                    CU            CD          CO          NI

                 16.00         <3.00           .       39.00
                  6.00         <3.00           .       22.00
                  3.00          6.00           .        8.00

                    PB            ZN          AL          CR

                 10.00         37.00    34000.00           .
                 18.00         33.00           .       18.00
                  7.00         16.00           .       10.00

                    AG            MN          FE

                  2.00             .           .
                  3.00             .           .
                  3.00             .           .
```

(continued)

Reproduced from
best available copy.

TABLE B-6 (continued)

SITE 3

SITECODE	ID	BA	SE	AS	CU	CD	CO	NI	PB	ZN	AL	CR	AG	MN	FE
3122481	1(30-36)	•	•	•	2.00	<3.00	•	34.00	•	36.00	16170.00	•	2.00	•	•
	1(44-48)	•	•	•	20.00	<3.00	•	22.00	•	40.00	14670.00	•	<1.00	•	•
	1(48-52)	•	•	•	60.00	<3.00	•	58.00	•	67.00	20830.00	•	3.00	•	•
	1(52-56)	•	•	•	17.00	<3.00	•	49.00	•	93.00	23000.00	•	6.00	•	•
	2(32-36)	•	•	•	37.00	<3.00	•	121.00	•	64.00	25170.00	•	1.00	•	•
	2(42-45)	•	•	•	29.00	<3.00	•	55.00	•	120.00	24670.00	•	2.00	•	•
	3(27-30)	•	•	•	62.00	<3.00	•	45.00	•	47.00	26000.00	•	1.00	•	•
	3(35-39)	•	•	•	56.00	<3.00	•	42.00	•	50.00	20000.00	•	1.00	•	•
	3(45-48)	•	•	•	50.00	<3.00	•	34.00	•	•	21670.00	•	1.00	•	•

(continued)

Reproduced from best available copy.

TABLE B-6 (continued)

SITE 3

SITECODE	ID	BA	SE	AS	CU	CD	CO	NI	PB	ZN	AL	CR	AG	MN	FE
3122881	BGD(30-35)	107.00	.	.	94.00	<3.00	.	9.00	27.00	40.00	.	18.00	3.00	.	.
	BGD(46-51)	64.00	.	.	8.00	<3.00	.	10.00	11.00	33.00	.	19.00	3.00	.	.

(continued)

Reproduced from best available copy.

TABLE B-6 (continued)

SITE 3

SITECODE	ID	BA	SE	AS	CU	CD	CO	NI	PB	ZN	AL	CR	AG	MN	FE
3062V82S	8GD(30-35)	107.00	.	.	94.00	<3.00	.	9.00	27.00	40.00	.	18.00	3.00	.	.
	8GD(46-51)	84.00	.	.	8.00	<1.00	.	10.00	11.00	33.00	.	19.00	3.00	.	.
	2(28-32)	39.00	.	.	6.00	<1.00	.	19.00	33.00	46.00	.	20.00	3.00	.	.
	2(45-48)	53.00	.	.	17.00	<3.00	.	37.00	36.00	86.00	.	36.00	3.00	.	.
	6(32-34)	61.00	.	.	44.00	<3.00	.	43.00	7.00	81.00	.	37.00	4.00	.	.
	6(52-56)	75.00	.	.	20.00	<1.00	.	25.00	14.00	88.00	.	47.00	3.00	.	.
	8GT	.	.	.	15.00	<3.00	7.00	40.00	30.00	5.00	17810.00	20.00	4.00	.	.
	BGB	.	.	0.00	8.00	<3.00	13.00	16.00	23.00	0.00	13500.00	30.00	2.00	.	.

Reproduced from best available copy.

APPENDIX C

CONCENTRATIONS OF ORGANIC COMPOUNDS FOUND IN SITE SOIL

Table C-1 Compounds Present in Backgound Samples

Compound	Concentration in Background Sample (mg/kg)	
	Top (0-25 cm)	Bottom (25-51 cm)
Site 1		
Chrysene	<.001	
Bis(2-ethylhexyl)phthalate	0.538	0.520
		.077
Benzo(b)fluoranthene		0.721
Benzo(k)fluoranthene	0.220	0.721
Benzo(a)anthracene	<.001	
Phenol		<.001
Site 2		
1,2-Diphenylhydrazine	<.001	<.001
Butylbenzylphthalate		<.001
Bis(2-ethylhexyl)phthalate	<.001	
Chrysene	.008	
Benzo(a)anthracene	.008	
2-Nitrophenol		0.102
4-Nitrophenol		.006
Site 3		
Ethylbenzene		.003
Bis(2-ethylhexyl)phthalate	<.001	0.801
	16.57	
Naphthalene	.002	
Isophorone	<.001	
Pyrene	.001	
Chrysene	<.001	
Benzo(a)anthracene	<.001	
Toluene	4.92	

Table C-2 Organic Compounds in Soil at Site 1

Compound	Concentration mg/kg					
	11/10/81		6/14/82		12/1/82	
	Top	Bottom	Top	Bottom	Top	Bottom
Benzo(b)fluoranthene		<.001			.010	.036
					62.400	
Benzo(k)fluoranthene		<.001		.036	.010	.036
					68.400	
Benzo(a)anthracene	78.80	<.001	.003	<.001	3.686	12.810
	1.976	<.001		.003		
	26.60					
	17.08 x 10^3					
	874.00					
Phenanthrene	.006	<.001	<.001	<.001		
	.003			<.001		
	.001	<.001				
	.012	<.001				
	<.091					
Fluoranthene	.012	<.001	<.001	<.001		
	.193			.001		
	14.700					
	.002					

(continued)

Table C-2 (continued)

Compound	Concentration mg/kg					
	11/10/81		6/14/82		12/1/82	
	Top	Bottom	Top	Bottom	Top	Bottom
Butylbenzylphthalate	.009 <.001 .104 .002 <.001	<.001 <.001	<.001	<.001 <.001		
Benzo(a)pyrene		4482.00 .332			.026 7.24	
Dibenzo(a,L)anthracene					<.001 135.90	.019
Benzo(g,h,i)perylene					.002 229.10	0.200
Anthracene	.006 .001 .002 .009 <.001	<.001 <.001	<.001 <.001	<.001 <.001		
Naphthalene	.053		<.001 <.001	<.001		

(continued)

Table C-2 (continued)

Compound	Concentration mg/kg					
	11/10/81		6/14/82		12/1/82	
	Top	Bottom	Top	Bottom	Top	Bottom
Benzene	.021					
	<.001					
	<.001					
	<.001					
Pyrene	3.142	<.001	<.001	.001		
	.358	<.001		<.001		
	9.594					
	14.924					
Toluene	<.001					
	.002					
	.011					
Ethylbenzene	<.001					
	<.001					
	<.001					
Di-n-butylphthalate						
Chyrsene			<.001	<.001	<.001	<.001
			<.001	.003		
Bis(2-ethyhexyl)phthalate	.073	<.001	<.001	<.001	<.001	<.001
	.006		<.001			
Isophorone			<.001			

(continued)

Table C-2 (continued)

Compound	Concentration mg/kg					
	11/10/81		6/14/82		12/1/82	
	Top	Bottom	Top	Bottom	Top	Bottom
Phenol	<.001	<.001	.0234	.1170	8.957	.1073
	.031		1.863		5.770	129.0
	<.001		.0141		42.980	
	<.001				30.700	
	<.001					
Pentachlorophenol	<.001					
	<.001					

Table C-3 Organic Compounds in Soil at Site 3

Compound	Concentration mg/kg					
	11/17/81		6/29/82		10/19/82	
	Top	Bottom	Top	Bottom	Top	Bottom
Chrysene			<.001			
			<.001			
Benzo(a)anthracene			<.001		.002	.002
			.0002		1.421	
Bis(2-ethylhexyl)phthalate	.196		<.001		.012	
	.167		<.001			
Isophorone			<.001			
			<.001			
			<.001			
2,6-Dinitrotoluene	.806	1.586	<.001			
	4.53	.005				
	.038	.023				
	.052					
N-Nitrosodiphenylamine			<.001			
Dibenzo(a,h)anthracene					<.001	<.001
					.005	
					.016	
Benzo(a)pyrene					.095	

(continued)

Table C-3 (continued)

Compound	Concentration mg/kg					
	11/17/81		6/29/82		10/19/82	
	Top	Bottom	Top	Bottom	Top	Bottom
Fluoranthene	.091	2.059				
	.024					
Phenol					0.220	.288
					0.058	
Benzene	.034	<.001				
	<.001					
	<.001					
	.005					
Bromoform	<.001	<.001				
		<.001				
Toluene	1.079	.653				
	5.790					
Ethylbenzene	<.001	.003				
	.006	.001				

Table C-4 Organic Compounds in Soil at Site 2

Compound	Concentration mg/kg					
	9//81 or 11/12/81		6/16/82		11/19/82	
	Top	Bottom	Top	Bottom	Top	Bottom
Anthracene	.318 6.520 <.001 .578 11.772	<.001	0.018			
Benzene	<.001 <.001 <.001 <.001	<.001				
Naphthalene	.264 9.480 .425		3.378 <.001			
Phenanthrene	.318 6.520 0.578 11.772 <.001	<.001 13.630				
1,2-Diphenylhydrazine			.011 0.448	.001		
Isophorone	.090 .222	.040				

(continued)

Table C-4 (continued)

Compound	Concentration mg/kg					
	9//81 or 11/12/81		6/16/82		11/19/82	
	Top	Bottom	Top	Bottom	Top	Bottom
Bis(2-ethylhexyl)phthalate			<.001	<.001		4.068
Pyrene	.062 .072	.131				
Butylbenzylphthalate			<.001	<.001		
Phenol	<.001 <.001 <.001 <.001	.001 <.001	.027			
4-Nitrophenol						.0013
Pentachlorophenol	.260 <.001	<.001				.2814
2-Nitrophenol			.849			

Table C-5 Organics Present in the Unsaturated Zone at Site 1

Deep Soil Cores

Compound	Concentration (mg/kg) Top	Bottom	# of +ve Observations
1,2-Diphenylhydrazine	.001	<.001	3
Acenaphthene		<.001	1
2,4-Dinitrotoluene	<.001	<.001	2

Soil Pore Water

Compound	Concentration (mg/l)	# of +ve Observations
Phenol	.122 .067 .052	3
Bis(2-ethylhexyl)-phthalate	120.80 55.64	2
Di-n-butylphthalate	.031	1
Butylbenzylphthalate	.036	1
Chrysene	.631	1

Table C-6 Organics Present in the Unsaturated Zone at Site 2

Deep Soil Cores

Compound	Concentration (mg/kg) Top	Bottom	# of +ve Observations
1,2-Diphenylhydrazine	.010	.010 .056	3
Anthracene	<.001	-	1
Bis(2-ethylhexyl)-phthalate	<.001 .008	-	2
Isophorone	<.001		1
Acenaphthylene		<.001	1
Fluorene	<.001	<.001	2
Diethylphthalate	<.001	-	1
Butylbenzylphthalate	<.001	-	1
2-Nitrophenol	0.676	-	1
4-Nitrophenol	0.384	-	1
2,4-Dichlorophenol	0.010	-	1
Phenol	0.089	0.138	2

Soil Pore Water

Compound	Concentration (mg/l)	No. of +ve Observations
Phenol	<.001	1
4-Nitrophenol	<.001	1
Pentachlorophenol	<.001	1

Table C-7 Organics Present in the Unsaturated Zone at Site 3

Deep Soil Cores

Compound	Concentration (mg/kg) Top	 Bottom	# of +ve Observations
Anthracene	-	1.28	1
Phenanthrene	1.32	16.90	2
Pyrene	1.17	13.16	2
Di-n-butylphthalate	.352 4.76	-	2
Butylbenzylphthalate	12.02 650.90	80.80	3
Chrysene	0.284	3.49	2
Bis(2-ethylhexyl) phthalate	6.19 140.5	8.87	3
Benzo(a) anthracene	0.396	3.76	2
Benzo(b) fluoranthene	.056	-	1
Benzo(k) fluoranthene	.044	-	1
Benzo(a) pyrene	0.394	-	1
2,4-Dichlorophenol	0.069	-	1
2,6-Dinitrotoluene	0.515	-	1
Soil Pore Water			
Phenol	< .001		1

Table C-8 Organic Compounds Found in the Background Samples of the Unsaturated Zone

Compound	Concentrations (mg/kg) Top	Bottom
Site 1		
1,2-Diphenylhydrazine	0.040	-
Site 2		
1,2-Diphenylhydrazine	-	.001
Anthracene		<.001
Bis(2-ethylhexyl)phthalate		<.001
2-Nitrophenol	1.166	-
4-Nitrophenol	0.662	.097
Site 3		
Phenol	-	0.273

Quality Control/Quality Assurance

A QC/QA program was implemented at the beginning of the project. This program had two main parts. Part 1 involved sample collection, transportation and storage, and Part 2 involved the determination of blanks, replicates and spikes.

Each sample collected was assigned an identifying code, which contained information on the site, date and type of sample collected. Samples were placed in a cooler immediately upon collection, to keep them cool until they could be refrigerated. The samples were stored in a refrigerator dedicated to project samples, until they were analyzed. Soil samples were collected in ziploc plastic bags and aqueous samples in borosilicate glass bottles with teflon-faced screw caps. A log book of all site visits and samples collected was maintained. Aqueous samples to be analyzed for metals were adjusted to pH <2 with nitric acid as soon as they arrived at the laboratory. pH and COD analyses were performed on the samples within 24 hours of collection. Soil samples were refrigerated at 4°C until they were analyzed. All samples for priority pollutant analysis were extracted within one week of collection, and analyzed within one month of extraction in most cases.

Glassware used for priority pollutant analysis was solvent washed, detergent washed, rinsed with tap water, distilled water and oven-dried. The K-D flasks and concentrators were also soaked in chromic acid prior to each set of extractions. After each batch of samples from one site was run, the glassware was also fired in a furnace of 400°C after the cleaning sequence described above.

Glassware for metals analysis was washed with detergent, and then acid-rinsed with nitric and hydrochloric acids. After a final rinse with distilled water, the glassware was oven-dried. Glassware used for other analyses were cleaned using standard laboratory procedures.

The quality control procedures used in the determination of organics centered mainly on the determination of blanks and the use of duplicate determinations. Some spikes were also determined, particularly on the aqueous samples. No studies were done on recoveries from the different soil matrices, because of time and money restrictions.

Duplicates, spikes and blanks were also run on the samples analyzed for metals. The duplicate determinations are included in the raw data for metals in Appendix B.

Procedural blanks were run with every set of Extraction Procedure Toxicity determinations. Ultrex nitric acid from J.T. Baker Chemical Co., was used in the digestion of the extract for metal analysis. These blanks served as controls for the level of metal contamination introduced by the extraction and filtration steps, as well as the digestion step.

In all cases, the concentrations of the blanks were subtracted before the final metal concentrations were calculated. Table C-9 lists blanks for soil pore water, E.P. Toxicity and soil core samples.

TABLE C-9 BLANK CONCENTRATIONS mg/l

	Cu	Ni	Zn	Ba	Cr	Al	Pb	As	Cd	Fe	Mn	Ag
Soil Pore Water												
Blank #1	.02	<.008	.46	.26	<.01	.20	.15	.108	<.01	.049	.007	.006
Blank #2	.03	<.008	.04	<.02	.05	.10	<.02	-	-	.090	.010	.014
E.P. Toxicity												
Blank #1	<.002	<.008	.31	.29	<.01	.22	<.02	-	.02	-	-	.03
Blank #2	.02	.130	.10	.20	.01	.35	.10	-	.01	-	-	<.002
Blank #3	.01	.015	.19	.28	.02	.29	<.02	-	<.01	-	-	.011
Blank #4	.01	.010	.16	-	.08	.20	.03	-	<.01	-	-	.010
Soil Samples												
Blank #1	<.002	<.008	.01	.11	<.01	-	<.02	-	<.01	-	-	.013
Blank #2	.01	.010	.03	.15	.08	-	.03	-	<.01	-	-	.010

APPENDIX D

Field Data for Trees

SPECIES	TREE	AREA	DATE	HEIGHT	WIDTH	DEATH
black locust	1	A	APR0782	29.80	0.95	
black locust	1	A	JUL2782	51.00	1.25	
black locust	1	A	SEP0882	52.00	1.13	
black locust	2	A	APR0782	22.90	0.64	
black locust	2	A	JUL2782	21.50	1.06	Y
black locust	2	A	SEP0882	.	.	Y
black locust	3	A	APR0782	21.60	0.32	
black locust	3	A	JUL2782	48.00	0.71	
black locust	3	A	SEP0882	.	.	Y
black locust	4	A	APR0782	24.10	0.32	
black locust	4	A	JUL2782	27.20	1.54	
black locust	4	A	SEP0882	.	.	Y
black locust	5	A	APR0782	24.10	0.64	
black locust	5	A	JUL2782	73.60	1.30	
black locust	5	A	SEP0882	80.00	1.23	
black locust	6	A	APR0782	22.90	0.64	
black locust	6	A	JUL2782	45.60	0.90	
black locust	6	A	SEP0882	.	.	Y
black locust	7	A	APR0782	25.40	0.48	
black locust	7	A	JUL2782	32.00	.	Y
black locust	7	A	SEP0882	.	.	Y
black locust	8	A	APR0782	22.20	0.48	
black locust	8	A	JUL2782	25.80	0.72	
black locust	8	A	SEP0882	25.40	1.25	
black locust	9	A	APR0782	24.10	0.32	
black locust	9	A	JUL2782	46.70	0.91	
black locust	9	A	SEP0882	39.50	0.86	
black locust	10	A	APR0782	.	.	
black locust	10	A	JUL2782	.	.	
black locust	10	A	SEP0882	.	.	
hackberry	1	A	APR0782	19.68	0.32	
hackberry	1	A	JUL2782	10.30	0.20	Y
hackberry	1	A	SEP0882	.	.	Y
hackberry	2	A	APR0782	34.30	0.32	
hackberry	2	A	JUL2782	30.20	0.44	
hackberry	2	A	SEP0882	29.50	0.41	
hackberry	3	A	APR0782	17.80	0.16	
hackberry	3	A	JUL2782	13.90	0.20	Y
hackberry	3	A	SEP0882	.	.	Y
hackberry	4	A	APR0782	22.90	0.16	
hackberry	4	A	JUL2782	16.30	0.20	Y
hackberry	4	A	SEP0882	.	.	Y
hackberry	5	A	APR0782	32.40	0.32	
hackberry	5	A	JUL2782	21.00	0.38	Y

Field Data for Trees

SPECIES	TREE	AREA	DATE	HEIGHT	WIDTH	DEATH
black locust	1	A	APR0782	29.80	0.95	
black locust	1	A	JUL2782	51.00	1.25	
black locust	1	A	SEP0882	52.00	1.13	
black locust	2	A	APR0782	22.90	0.64	
black locust	2	A	JUL2782	21.50	1.06	Y
black locust	2	A	SEP0882	.	.	Y
black locust	3	A	APR0782	21.60	0.32	
black locust	3	A	JUL2782	48.00	0.71	
black locust	3	A	SEP0882	.	.	Y
black locust	4	A	APR0782	24.10	0.32	
black locust	4	A	JUL2782	27.20	1.54	
black locust	4	A	SEP0882	.	.	Y
black locust	5	A	APR0782	24.10	0.64	
black locust	5	A	JUL2782	73.60	1.30	
black locust	5	A	SEP0882	80.00	1.23	
black locust	6	A	APR0782	22.90	0.64	
black locust	6	A	JUL2782	45.60	0.90	
black locust	6	A	SEP0882	.	.	Y
black locust	7	A	APR0782	25.40	0.48	
black locust	7	A	JUL2782	32.00	.	Y
black locust	7	A	SEP0882	.	.	Y
black locust	8	A	APR0782	22.20	0.48	
black locust	8	A	JUL2782	25.80	0.72	
black locust	8	A	SEP0882	25.40	1.25	
black locust	9	A	APR0782	24.10	0.32	
black locust	9	A	JUL2782	46.70	0.91	
black locust	9	A	SEP0882	39.50	0.86	
black locust	10	A	APR0782	.	.	
black locust	10	A	JUL2782	.	.	
black locust	10	A	SEP0882	.	.	
hackberry	1	A	APR0782	19.68	0.32	
hackberry	1	A	JUL2782	10.30	0.20	Y
hackberry	1	A	SEP0882	.	.	Y
hackberry	2	A	APR0782	34.30	0.32	
hackberry	2	A	JUL2782	30.20	0.44	
hackberry	2	A	SEP0882	29.50	0.41	
hackberry	3	A	APR0782	17.80	0.16	
hackberry	3	A	JUL2782	13.90	0.20	Y
hackberry	3	A	SEP0882	.	.	Y
hackberry	4	A	APR0782	22.90	0.16	
hackberry	4	A	JUL2782	16.30	0.20	Y
hackberry	4	A	SEP0882	.	.	Y
hackberry	5	A	APR0782	32.40	0.32	
hackberry	5	A	JUL2782	21.00	0.38	Y

Field Data for Trees

SPECIES	TREE	AREA	DATE	HEIGHT	WIDTH	DEATH
hackberry	5	A	SEP0882	.	.	Y
hackberry	6	A	APR0782	26.00	0.32	
hackberry	6	A	JUL2782	18.40	0.30	Y
hackberry	6	A	SEP0882	.	.	Y
hackberry	7	A	APR0782	38.10	0.32	
hackberry	7	A	JUL2782	34.30	0.36	
hackberry	7	A	SEP0882	.	.	Y
hackberry	8	A	APR0782	27.90	0.48	
hackberry	8	A	JUL2782	20.40	0.34	
hackberry	8	A	SEP0882	.	.	Y
hackberry	9	A	APR0782	22.90	0.32	
hackberry	9	A	JUL2782	18.40	0.40	Y
hackberry	9	A	SEP0882	.	.	Y
hackberry	10	A	APR0782	.	.	
hackberry	10	A	JUL2782	.	.	
hackberry	10	A	SEP0882	.	.	
osage orange	1	A	APR0782	16.50	1.11	
osage orange	1	A	JUL2782	29.10	0.64	Y
osage orange	1	A	SEP0882	27.90	.	R
osage orange	2	A	APR0782	15.20	1.27	
osage orange	2	A	JUL2782	17.30	0.50	
osage orange	2	A	SEP0882	15.00	0.67	R
osage orange	3	A	APR0782	26.70	0.64	
osage orange	3	A	JUL2782	34.00	.	Y
osage orange	3	A	SEP0882	.	.	Y
osage orange	4	A	APR0782	16.50	1.27	
osage orange	4	A	JUL2782	17.60	0.36	
osage orange	4	A	SEP0882	14.80	0.58	R
osage orange	5	A	APR0782	24.10	1.27	
osage orange	5	A	JUL2782	15.10	0.52	Y
osage orange	5	A	SEP0882	.	.	Y
osage orange	6	A	APR0782	25.40	1.11	
osage orange	6	A	JUL2782	15.80	0.74	
osage orange	6	A	SEP0882	14.20	0.52	
osage orange	7	A	APR0782	17.10	0.79	
osage orange	7	A	JUL2782	15.30	0.41	Y
osage orange	7	A	SEP0882	7.50	.	R
osage orange	8	A	APR0782	27.70	0.64	
osage orange	8	A	JUL2782	23.80	0.49	Y
osage orange	8	A	SEP0882	20.20	0.43	R
osage orange	9	A	APR0782	26.70	0.79	
osage orange	9	A	JUL2782	16.20	0.30	Y
osage orange	9	A	SEP0882	.	.	
osage orange	10	A	APR0782	.	.	
osage orange	10	A	JUL2782	.	.	
osage orange	10	A	SEP0882	.	.	
red cedar	1	A	APR0782	33.60	0.32	

Field Data for Trees

SPECIES	TREE	AREA	DATE	HEIGHT	WIDTH	DEATH
red cedar	1	A	JUL2782	31.00	0.51	
red cedar	1	A	SEP0882	28.20	1.05	
red cedar	2	A	APR0782	30.50	0.64	
red cedar	2	A	JUL2782	32.20	0.67	
red cedar	2	A	SEP0882	26.50	0.68	
red cedar	3	A	APR0782	27.90	0.95	
red cedar	3	A	JUL2782	33.90	1.90	
red cedar	3	A	SEP0882	29.00	1.09	
red cedar	4	A	APR0782	36.20	0.95	
red cedar	4	A	JUL2782	42.10	1.49	
red cedar	4	A	SEP0882	36.00	1.02	
red cedar	5	A	APR0782	34.90	0.95	
red cedar	5	A	JUL2782	34.90	1.10	
red cedar	5	A	SEP0882	32.50	0.65	
red cedar	6	A	APR0782	29.20	0.64	
red cedar	6	A	JUL2782	32.20	0.76	
red cedar	6	A	SEP0882	30.00	0.78	
red cedar	7	A	APR0782	34.30	0.64	
red cedar	7	A	JUL2782	35.00	0.65	
red cedar	7	A	SEP0882	33.80	0.67	
red cedar	8	A	APR0782	30.50	0.64	
red cedar	8	A	JUL2782	32.40	0.66	
red cedar	8	A	SEP0882	31.00	0.60	
red cedar	9	A	APR0782	29.20	0.48	
red cedar	9	A	JUL2782	31.60	0.48	
red cedar	9	A	SEP0882	30.50	0.46	
red cedar	10	A	APR0782	.	.	
red cedar	10	A	JUL2782	.	.	
red cedar	10	A	SEP0882	.	.	
russian olive	1	A	APR0782	15.20	0.79	
russian olive	1	A	JUL2782	16.90	0.79	Y
russian olive	1	A	SEP0882	.	.	Y
russian olive	2	A	APR0782	22.80	0.64	
russian olive	2	A	JUL2782	20.50	.	Y
russian olive	2	A	SEP0882	.	.	Y
russian olive	3	A	APR0782	20.30	1.27	
russian olive	3	A	JUL2782	26.90	0.31	Y
russian olive	3	A	SEP0882	.	.	Y
russian olive	4	A	APR0782	14.60	0.32	
russian olive	4	A	JUL2782	.	.	Y
russian olive	4	A	SEP0882	.	.	Y
russian olive	5	A	APR0782	22.90	0.64	
russian olive	5	A	JUL2782	26.50	0.57	
russian olive	5	A	SEP0882	.	.	Y
russian olive	6	A	APR0782	38.10	1.27	
russian olive	6	A	JUL2782	36.00	1.60	
russian olive	6	A	SEP0882	29.00	1.50	

Field Data for Trees

SPECIES	TREE	AREA	DATE	HEIGHT	WIDTH	DEATH
russian olive	7	A	APR0782	16.50	0.32	
russian olive	7	A	JUL2782	26.60	0.43	
russian olive	7	A	SEP0882	.	.	Y
russian olive	8	A	APR0782	15.20	0.64	
russian olive	8	A	JUL2782	12.40	0.50	Y
russian olive	8	A	SEP0882	.	.	Y
russian olive	9	A	APR0782	16.50	0.64	
russian olive	9	A	JUL2782	23.80	0.54	
russian olive	9	A	SEP0882	13.50	0.61	
russian olive	10	A	APR0782	.	.	
russian olive	10	A	JUL2782	.	.	
russian olive	10	A	SEP0882	.	.	
black locust	1	B	APR0782	20.30	0.32	
black locust	1	B	JUL2782	28.00	1.01	
black locust	1	B	SEP0882	.	.	Y
black locust	2	B	APR0782	22.90	0.32	
black locust	2	B	JUL2782	17.00	0.99	
black locust	2	B	SEP0882	.	.	Y
black locust	3	B	APR0782	30.00	0.32	
black locust	3	B	JUL2782	19.30	0.97	
black locust	3	B	SEP0882	.	.	Y
black locust	4	B	APR0782	19.10	0.16	
black locust	4	B	JUL2782	21.00	1.02	
black locust	4	B	SEP0882	.	.	Y
black locust	5	B	APR0782	14.00	0.32	
black locust	5	B	JUL2782	16.00	0.94	
black locust	5	B	SEP0882	.	.	Y
black locust	6	B	APR0782	21.60	0.32	
black locust	6	B	JUL2782	.	.	Y
black locust	6	B	SEP0882	.	.	Y
black locust	7	B	APR0782	33.00	0.32	
black locust	7	B	JUL2782	22.50	0.71	
black locust	7	B	SEP0882	.	.	Y
black locust	8	B	APR0782	17.10	0.48	
black locust	8	B	JUL2782	.	.	Y
black locust	8	B	SEP0882	.	.	Y
black locust	9	B	APR0782	22.90	0.48	
black locust	9	B	JUL2782	21.00	0.64	
black locust	9	B	SEP0882	.	.	Y
black locust	10	B	APR0782	14.00	0.32	
black locust	10	B	JUL2782	24.30	0.74	
black locust	10	B	SEP0882	.	.	Y
hackberry	1	B	APR0782	26.70	0.32	
hackberry	1	B	JUL2782	28.00	0.28	
hackberry	1	B	SEP0882	.	.	Y
hackberry	2	B	APR0782	31.10	0.32	
hackberry	2	B	JUL2782	29.50	0.29	

Field Data for Trees

SPECIES	TREE	AREA	DATE	HEIGHT	WIDTH	DEATH
hackberry	2	B	SEP0882	24.50	0.38	
hackberry	3	B	APR0782	17.10	0.32	
hackberry	3	B	JUL2782	14.50	0.19	
hackberry	3	B	SEP0882	.	.	Y
hackberry	4	B	APR0782	29.20	0.32	
hackberry	4	B	JUL2782	26.60	0.26	
hackberry	4	B	SEP0882	.	.	Y
hackberry	5	B	APR0782	26.70	0.16	
hackberry	5	B	JUL2782	24.00	0.28	
hackberry	5	B	SEP0882	.	.	Y
hackberry	6	B	APR0782	19.10	0.16	
hackberry	6	B	JUL2782	18.00	0.20	Y
hackberry	6	B	SEP0882	.	.	Y
hackberry	7	B	APR0782	27.90	0.32	
hackberry	7	B	JUL2782	26.00	0.18	
hackberry	7	B	SEP0882	.	.	Y
hackberry	8	B	APR0782	22.90	0.32	
hackberry	8	B	JUL2782	10.00	0.28	Y
hackberry	8	B	SEP0882	.	.	Y
hackberry	9	B	APR0782	12.70	0.16	
hackberry	9	B	JUL2782	14.00	0.14	
hackberry	9	B	SEP0882	.	.	Y
hackberry	10	B	APR0782	20.30	0.16	
hackberry	10	B	JUL2782	22.00	0.23	
hackberry	10	B	SEP0882	.	.	Y
osage orange	1	B	APR0782	25.40	0.95	
osage orange	1	B	JUL2782	19.50	0.25	
osage orange	1	B	SEP0882	.	.	Y
osage orange	2	B	APR0782	15.20	1.11	
osage orange	2	B	JUL2782	20.50	0.18	
osage orange	2	B	SEP0882	.	.	Y
osage orange	3	B	APR0782	17.80	1.11	
osage orange	3	B	JUL2782	25.00	0.30	
osage orange	3	B	SEP0882	3.90	0.19	
osage orange	4	B	APR0782	19.10	1.27	
osage orange	4	B	JUL2782	18.30	0.25	
osage orange	4	B	SEP0882	10.40	0.23	
osage orange	5	B	APR0782	15.20	1.11	
osage orange	5	B	JUL2782	13.00	0.17	
osage orange	5	B	SEP0882	.	.	Y
osage orange	6	B	APR0782	16.50	1.27	
osage orange	6	B	JUL2782	19.00	0.21	
osage orange	6	B	SEP0882	.	.	Y
osage orange	7	B	APR0782	14.00	0.95	
osage orange	7	B	JUL2782	.	.	Y
osage orange	7	B	SEP0882	.	.	Y
osage orange	8	B	APR0782	20.30	0.95	

Field Data for Trees

SPECIES	TREE	AREA	DATE	HEIGHT	WIDTH	DEATH
osage orange	8	B	JUL2782	.	.	Y
osage orange	8	B	SEP0882	.	.	Y
osage orange	9	B	APR0782	17.80	0.64	
osage orange	9	B	JUL2782	25.00	0.35	
osage orange	9	B	SEP0882	.	.	Y
osage orange	10	B	APR0782	20.30	0.95	
osage orange	10	B	JUL2782	13.00	0.19	
osage orange	10	B	SEP0882	.	.	Y
red cedar	1	B	APR0782	28.60	0.64	
red cedar	1	B	JUL2782	28.70	0.44	
red cedar	1	B	SEP0882	21.80	0.57	
red cedar	2	B	APR0782	29.80	0.64	
red cedar	2	B	JUL2782	34.00	0.79	
red cedar	2	B	SEP0882	29.50	0.62	
red cedar	3	B	APR0782	34.90	0.95	
red cedar	3	B	JUL2782	37.00	0.92	
red cedar	3	B	SEP0882	33.00	0.91	
red cedar	4	B	APR0782	34.30	1.11	
red cedar	4	B	JUL2782	35.00	0.86	
red cedar	4	B	SEP0882	29.80	0.75	
red cedar	5	B	APR0782	34.90	1.43	
red cedar	5	B	JUL2782	36.00	0.58	
red cedar	5	B	SEP0882	28.10	0.55	
red cedar	6	B	APR0782	36.80	0.48	
red cedar	6	B	JUL2782	38.00	0.45	
red cedar	6	B	SEP0882	31.00	0.48	
red cedar	7	B	APR0782	39.40	0.79	
red cedar	7	B	JUL2782	35.00	0.65	
red cedar	7	B	SEP0882	28.50	0.74	
red cedar	8	B	APR0782	34.90	0.64	
red cedar	8	B	JUL2782	29.00	0.49	
red cedar	8	B	SEP0882	25.90	0.48	
red cedar	9	B	APR0782	28.60	0.64	
red cedar	9	B	JUL2782	33.00	0.34	
red cedar	9	B	SEP0882	23.20	0.34	
red cedar	10	B	APR0782	29.80	0.32	
red cedar	10	B	JUL2782	32.00	0.31	
red cedar	10	B	SEP0882	24.00	0.28	
russian olive	1	B	APR0782	38.10	1.11	
russian olive	1	B	JUL2782	19.50	0.77	
russian olive	1	B	SEP0882	.	.	Y
russian olive	2	B	APR0782	22.90	0.64	
russian olive	2	B	JUL2782	20.00	0.70	
russian olive	2	B	SEP0882	.	.	Y
russian olive	3	B	APR0782	19.70	0.64	
russian olive	3	B	JUL2782	23.00	0.74	
russian olive	3	B	SEP0882	.	.	Y

Field Data for Trees

SPECIES	TREE	AREA	DATE	HEIGHT	WIDTH	DEATH
russian olive	4	B	APR0782	19.10	0.95	
russian olive	4	B	JUL2782	23.00	0.89	
russian olive	4	B	SEP0882	.	.	Y
russian olive	5	B	APR0782	20.30	0.64	
russian olive	5	B	JUL2782	23.00	0.71	
russian olive	5	B	SEP0882	.	.	Y
russian olive	6	B	APR0782	30.50	0.64	
russian olive	6	B	JUL2782	22.50	0.72	
russian olive	6	B	SEP0882	.	.	Y
russian olive	7	B	APR0782	15.20	0.64	
russian olive	7	B	JUL2782	10.00	0.61	
russian olive	7	B	SEP0882	.	.	Y
russian olive	8	B	APR0782	21.60	0.48	
russian olive	8	B	JUL2782	16.80	0.37	
russian olive	8	B	SEP0882	.	.	Y
russian olive	9	B	APR0782	17.80	0.48	
russian olive	9	B	JUL2782	.	.	Y
russian olive	9	B	SEP0882	.	.	Y
russian olive	10	B	APR0782	17.80	0.32	
russian olive	10	B	JUL2782	15.00	0.28	
russian olive	10	B	SEP0882	.	.	Y
black locust	1	C	APR0782	22.20	0.48	
black locust	1	C	JUL2782	201	1.59	
black locust	1	C	SEP0882	270	2.41	
black locust	2	C	APR0782	19.70	0.32	
black locust	2	C	JUL2782	213	1.91	
black locust	2	C	SEP0882	250	2.36	
black locust	3	C	APR0782	29.20	0.64	
black locust	3	C	JUL2782	232	2.41	
black locust	3	C	SEP0882	267	3.05	
black locust	4	C	APR0782	34.90	0.79	
black locust	4	C	JUL2782	230.5	1.88	
black locust	4	C	SEP0882	260	3.01	
black locust	5	C	APR0782	25.40	0.64	
black locust	5	C	JUL2782	173	1.81	
black locust	5	C	SEP0882	215	2.16	
black locust	6	C	APR0782	27.90	0.64	
black locust	6	C	JUL2782	237.5	2.09	
black locust	6	C	SEP0882	228	2.22	
black locust	7	C	APR0782	30.50	0.95	
black locust	7	C	JUL2782	200.5	1.64	
black locust	7	C	SEP0882	202	1.91	
black locust	8	C	APR0782	33.00	0.95	
black locust	8	C	JUL2782	101.5	1.17	
black locust	8	C	SEP0882	112	1.15	
black locust	9	C	APR0782	24.10	0.64	
black locust	9	C	JUL2782	181	1.92	

Field Data for Trees

SPECIES	TREE	AREA	DATE	HEIGHT	WIDTH	DEATH
black locust	9	C	SEP0882	185.5	1.99	
black locust	10	C	APR0782	27.90	0.48	
black locust	10	C	JUL2782	165.5	1.82	
black locust	10	C	SEP0882	199	2.99	
hackberry	1	C	APR0782	24.10	0.32	
hackberry	1	C	JUL2782	40.00	0.35	
hackberry	1	C	SEP0882	40.00	0.46	
hackberry	2	C	APR0782	15.20	0.16	
hackberry	2	C	JUL2782	52.50	0.37	
hackberry	2	C	SEP0882	8.50	0.38	
hackberry	3	C	APR0782	33.00	0.47	
hackberry	3	C	JUL2782	40.00	0.47	
hackberry	3	C	SEP0882	41.00	0.47	
hackberry	4	C	APR0782	21.60	0.32	
hackberry	4	C	JUL2782	36.00	0.48	
hackberry	4	C	SEP0882	34.50	0.37	
hackberry	5	C	APR0782	33.00	0.31	
hackberry	5	C	JUL2782	36.00	0.31	
hackberry	5	C	SEP0882	32.00	0.32	
hackberry	6	C	APR0782	27.90	0.32	
hackberry	6	C	JUL2782	27.50	0.30	
hackberry	6	C	SEP0882	26.50	0.30	
hackberry	7	C	APR0782	43.20	0.48	
hackberry	7	C	JUL2782	.	.	Y
hackberry	7	C	SEP0882	11.50	0.38	
hackberry	8	C	APR0782	33.00	0.32	
hackberry	8	C	JUL2782	17.50	0.38	
hackberry	8	C	SEP0882	17.50	0.31	
hackberry	9	C	APR0782	22.90	0.32	
hackberry	9	C	JUL2782	.	.	Y
hackberry	9	C	SEP0882	.	.	Y
hackberry	10	C	APR0782	33.00	0.48	
hackberry	10	C	JUL2782	24.50	0.38	
hackberry	10	C	SEP0882	24.60	0.36	
osage orange	1	C	APR0782	14.00	0.95	
osage orange	1	C	JUL2782	66.50	0.85	
osage orange	1	C	SEP0882	98.50	1.01	
osage orange	2	C	APR0782	17.80	1.11	
osage orange	2	C	JUL2782	75.50	0.93	
osage orange	2	C	SEP0882	95.50	1.06	
osage orange	3	C	APR0782	16.50	1.43	
osage orange	3	C	JUL2782	77.00	0.73	
osage orange	3	C	SEP0882	102	1.06	
osage orange	4	C	APR0782	19.10	0.95	
osage orange	4	C	JUL2782	87.00	0.83	
osage orange	4	C	SEP0882	125	0.95	
osage orange	5	C	APR0782	27.90	1.27	

Field Data for Trees

SPECIES	TREE	AREA	DATE	HEIGHT	WIDTH	DEATH
osage orange	5	C	JUL2782	74.00	0.87	
osage orange	5	C	SEP0882	92.50	0.91	
osage orange	6	C	APR0782	20.30	1.27	
osage orange	6	C	JUL2782	70.50	0.70	
osage orange	6	C	SEP0882	70.50	0.82	
osage orange	7	C	APR0782	25.40	1.27	
osage orange	7	C	JUL2782	43.00	0.72	
osage orange	7	C	SEP0882	70.00	0.78	
osage orange	8	C	APR0782	19.00	1.11	
osage orange	8	C	JUL2782	19.00	0.51	Y
osage orange	8	C	SEP0882	18.00	0.69	
osage orange	9	C	APR0782	33.00	1.27	
osage orange	9	C	JUL2782	43.00	0.56	
osage orange	9	C	SEP0882	48.50	0.63	
osage orange	10	C	APR0782	17.10	1.27	
osage orange	10	C	JUL2782	70.00	0.78	
osage orange	10	C	SEP0882	68.50	0.78	
red cedar	1	C	APR0782	33.70	0.64	
red cedar	1	C	JUL2782	37.50	0.73	
red cedar	1	C	SEP0882	39.50	0.73	
red cedar	2	C	APR0782	38.10	1.11	
red cedar	2	C	JUL2782	25.50	1.32	
red cedar	2	C	SEP0882	68.50	1.44	
red cedar	3	C	APR0782	39.40	0.64	
red cedar	3	C	JUL2782	8.00	0.65	
red cedar	3	C	SEP0882	14.50	0.60	
red cedar	4	C	APR0782	35.60	0.79	
red cedar	4	C	JUL2782	43.50	1.32	
red cedar	4	C	SEP0882	52.50	1.07	
red cedar	5	C	APR0782	33.00	0.79	
red cedar	5	C	JUL2782	46.50	0.85	
red cedar	5	C	SEP0882	54.50	0.92	
red cedar	6	C	APR0782	27.90	0.32	
red cedar	6	C	JUL2782	27.00	0.36	
red cedar	6	C	SEP0882	24.00	0.44	
red cedar	7	C	APR0782	31.80	0.64	
red cedar	7	C	JUL2782	33.00	0.79	
red cedar	7	C	SEP0882	40.50	0.69	
red cedar	8	C	APR0782	36.80	0.95	
red cedar	8	C	JUL2782	43.00	0.72	
red cedar	8	C	SEP0882	53.00	0.78	
red cedar	9	C	APR0782	30.50	0.64	
red cedar	9	C	JUL2782	46.00	0.81	
red cedar	9	C	SEP0882	52.00	0.92	
red cedar	10	C	APR0782	35.60	1.11	
red cedar	10	C	JUL2782	51.50	0.73	
red cedar	10	C	SEP0882	61.00	1.35	

Field Data for Trees

SPECIES	TREE	AREA	DATE	HEIGHT	WIDTH	DEATH
russian olive	1	C	APR0782	21.60	0.32	
russian olive	1	C	JUL2782	58.00	0.72	
russian olive	1	C	SEP0882	67.00	0.81	
russian olive	2	C	APR0782	24.10	0.32	
russian olive	2	C	JUL2782	.	.	Y
russian olive	2	C	SEP0882	.	.	Y
russian olive	3	C	APR0782	27.90	0.64	
russian olive	3	C	JUL2782	44.50	0.59	
russian olive	3	C	SEP0882	44.50	0.59	
russian olive	4	C	APR0782	21.60	0.64	
russian olive	4	C	JUL2782	20.00	0.62	
russian olive	4	C	SEP0882	17.00	0.55	Y
russian olive	5	C	APR0782	19.70	0.64	
russian olive	5	C	JUL2782	36.00	0.58	
russian olive	5	C	SEP0882	36.00	0.58	
russian olive	6	C	APR0782	20.30	0.32	
russian olive	6	C	JUL2782	.	.	Y
russian olive	6	C	SEP0882	.	.	Y
russian olive	7	C	APR0782	17.80	0.64	
russian olive	7	C	JUL2782	27.00	0.52	
russian olive	7	C	SEP0882	31.00	0.55	
russian olive	8	C	APR0782	32.40	0.64	
russian olive	8	C	JUL2782	30.50	0.55	
russian olive	8	C	SEP0882	24.00	0.53	Y
russian olive	9	C	APR0782	20.30	0.64	
russian olive	9	C	JUL2782	56.50	0.66	
russian olive	9	C	SEP0882	56.50	0.75	
russian olive	10	C	APR0782	22.90	0.64	
russian olive	10	C	JUL2782	67.00	0.97	
russian olive	10	C	SEP0882	70.50	1.05	

APPENDIX E

CLIMATOLOGICAL DATA

Table E1 Daily Rainfall Record*

DAY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT	OCT	NOV
1			.02	.05					.10
2		.30	.20					.50	
3				.22					
4									
5	.07		2.45		.04				
6			.09		2.70				
7		.02			.10	.10			
8						T			.02
9									
10		.32		.46	.01				.30
11			.04	.26				.09	.22
12			3.55						
13	.80		.03				.24		
14	.02	T			T		1.05		
15				.24	.03	T	.09		
16	T		1.35						T
17	T	.07	.03	.02				T	.01
18		.18	.02	.12					.01
19			.28				.03	T	
20	T		.01	.56					
21		T	.18	.04					
22			.02					.18	.03
23		.06	.80	.58			T		
24		.02	1.50	.82					.12
25		.82	.01						1.05
26	.40		.42	T					1.20
27	.18	.07	1.50	.15	.04	.14			.08
28		.30			T			1.25	
29	.06							.01	
30		.22	.86	2.00					
31				1.15					
Total	1.53	2.38	13.36	3.52	6.07	0.24	1.41	2.05	3.12
80 yr. Avg.	2.73	4.13	5.18	3.71	2.80	2.79	3.47	3.65	2.38

---

* Measurements in inches, T = trace amount, data from Noble Foundation headquarters farm.

Table E-2 Daily Temperature Record (°F)

Day	March		April		May		June		July	
	High	Low	High	Low	High	Low	High	Low	High	Low
1	66	33	78	46	76	54	80	50	90	70
2	68	45	82	65	75	54	78	56	91	72
3	68	48	76	41	80	58	87	62	92	72
4	53	35	70	50	83	60	77	62	93	74
5	35	32	64	54	75	64	84	57	91	76
6	48	28	60	36	59	48	86	65	88	67
7	58	30	50	42	76	43	88	69	87	66
8	71	40	62	52	77	48	87	69	92	65
9	65	43	58	44	78	54	89	70	94	70
10	71	43	60	37	80	58	86	64	93	71
11	71	56	68	37	74	60	83	62	91	66
12	76	53	82	52	66	57	85	62	92	69
13	70	49	88	54	74	58	85	57	94	68
14	65	48	82	52	79	58	87	62	92	66
15	76	49	80	63	83	55	76	70	92	67
16	80	48	89	64	81	63	80	60	93	72
17	82	50	73	49	80	54	86	58	93	74
18	78	64	58	48	77	56	82	64	94	75
19	83	64	82	52	84	60	86	65	96	72
20	77	52	64	54	82	65	88	62	96	70
21	68	48	64	48	90	63	83	61	99	72
22	66	42	71	40	83	61	90	62	101	71
23	70	38	71	42	85	61	87	65	99	72
24	72	46	59	46	80	60	86	62	97	70
25	59	47	75	51	82	63	88	62	95	68
26	54	36	79	48	84	62	87	64	97	70
27	45	37	77	48	87	63	89	65	97	69
28	62	40	67	53	85	63	91	64	95	72
29	60	42	78	46	90	68	95	68	92	74
30	74	58	64	52	88	70	92	71	87	72
31	76	51			72	58			79	68

Day	August		Sept		Oct		Nov	
	High	Low	High	Low	High	Low	High	Low
1	91	71	99	74	88	61	81	64
2	92	71	98	71	92	64	70	55
3	92	72	92	69	89	63	58	46
4	94	72	90	58	93	64	64	36
5	97	71	91	61	91	64	64	33
6	101	71	95	56	91	67	69	42
7	90	72	95	59	89	62	70	54

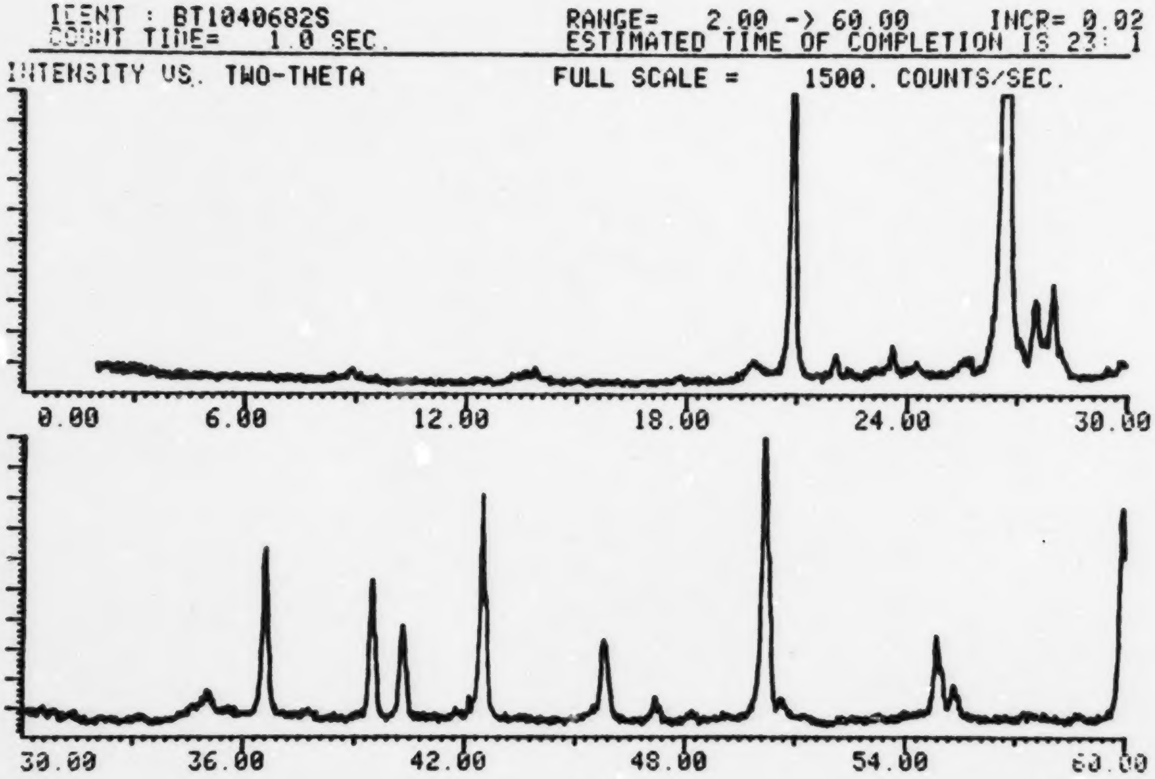
(continued)

Table E-2 (continued)

Day	August		Sept		Oct		Nov	
	High	Low	High	Low	High	Low	High	Low
8	92	70	92	62	86	70	66	51
9	94	68	93	60	76	53	73	55
10	94	70	94	65	73	51	70	58
11	94	71	94	66	75	47	70	60
12	96	71	97	68	68	51	54	45
13	98	73	89	70	79	52	54	28
14	99	73	95	70	79	45	52	36
15	100	71	79	64	80	48	55	26
16	100	70	88	64	85	48	59	40
17	91	71	95	64	77	53	50	44
18	90	70	85	64	86	56	60	47
19	94	66	73	61	82	63	77	57
20	96	65	77	60	63	41	78	55
21	97	66	74	50	49	43	77	40
22	99	68	80	46	72	49	79	56
23	99	71	88	56	74	41	53	32
24	98	74	84	60			42	29
25	96	70	81	54			39	32
26	98	71	76	48	74	60	40	36
27	102	74	86	61	77	38	39	38
28	92	68	88	66	68	54	59	32
29	96	70	87	66	76	42	67	34
30	100	70	87	68	75	52	74	42
31	98	72			81	66		

APPENDIX F

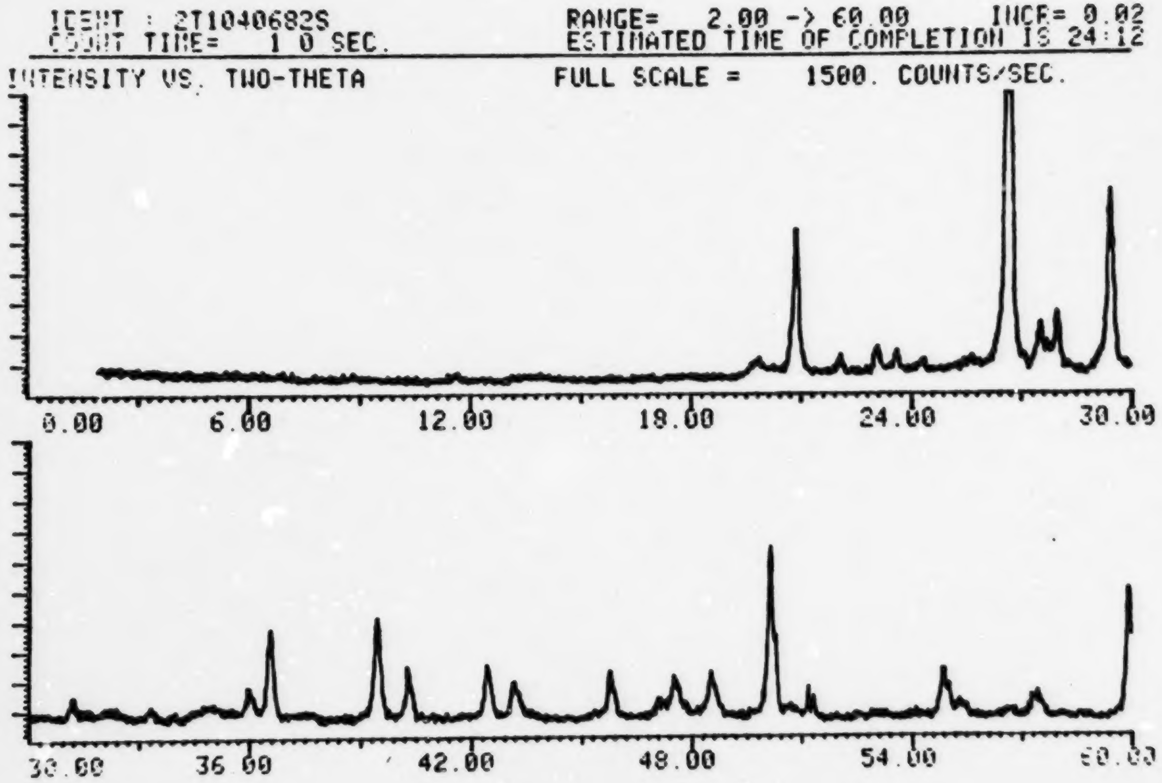
X-RAY DIFFRACTION SPECTRA



(continued)

Reproduced from
best available copy.

APPENDIX F (continued)

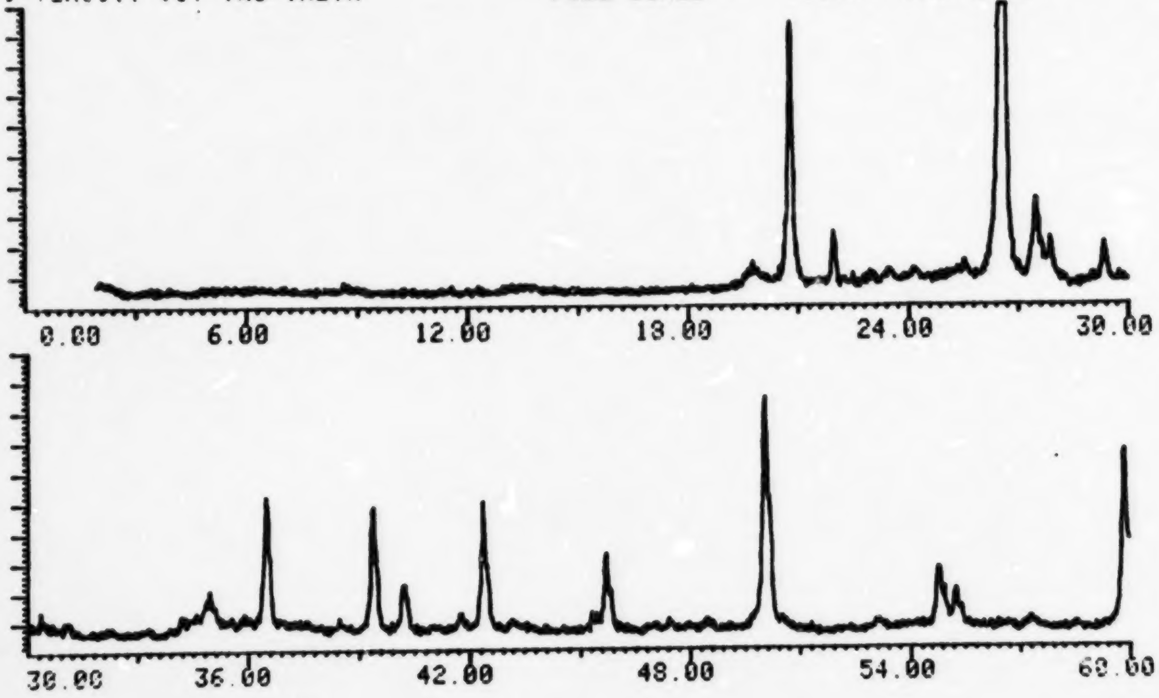


(continued)

Reproduced from
best available copy.

APPENDIX F (continued)

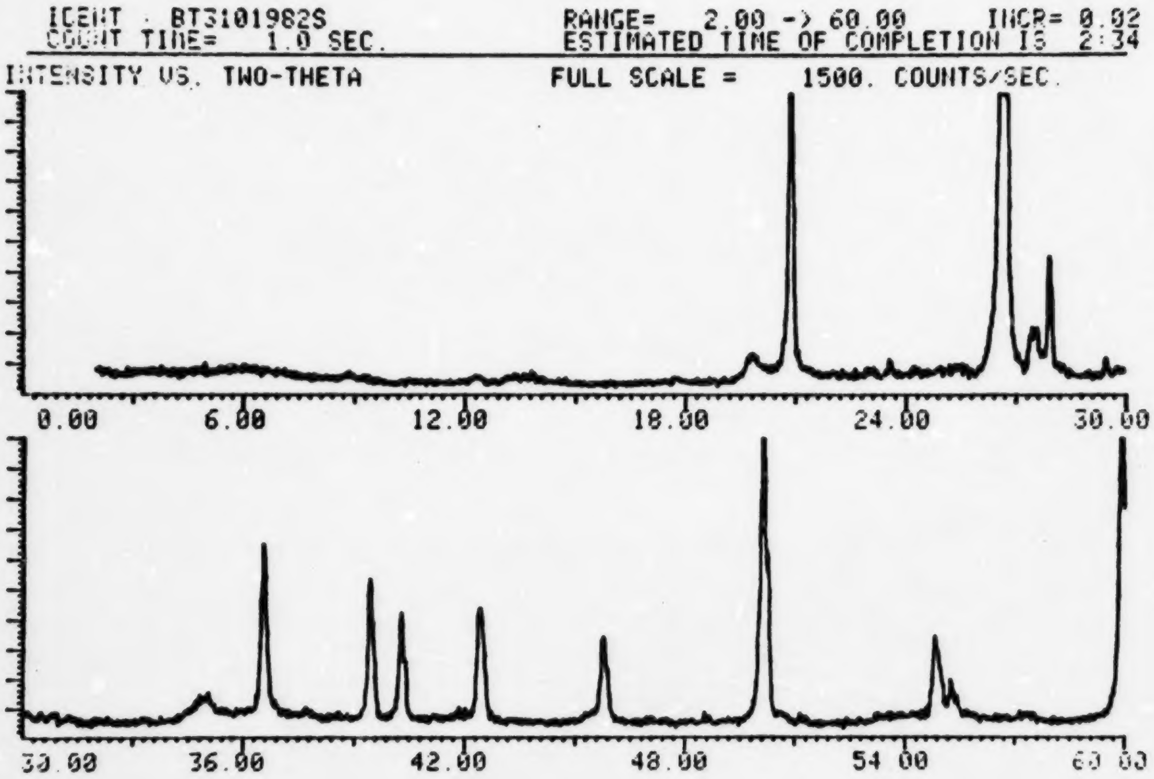
```
IDENT   4T1040682S                  RANGE=   2.00 -> 60.00      INCP= 0.02
COUNT TIME=   1.0 SEC.              ESTIMATED TIME OF COMPLETION IS  1:22
INTENSITY VS. TWO-THETA             FULL SCALE =    1500. COUNTS/SEC.
```



(continued)

Reproduced from
best available copy.

APPENDIX F (continued)

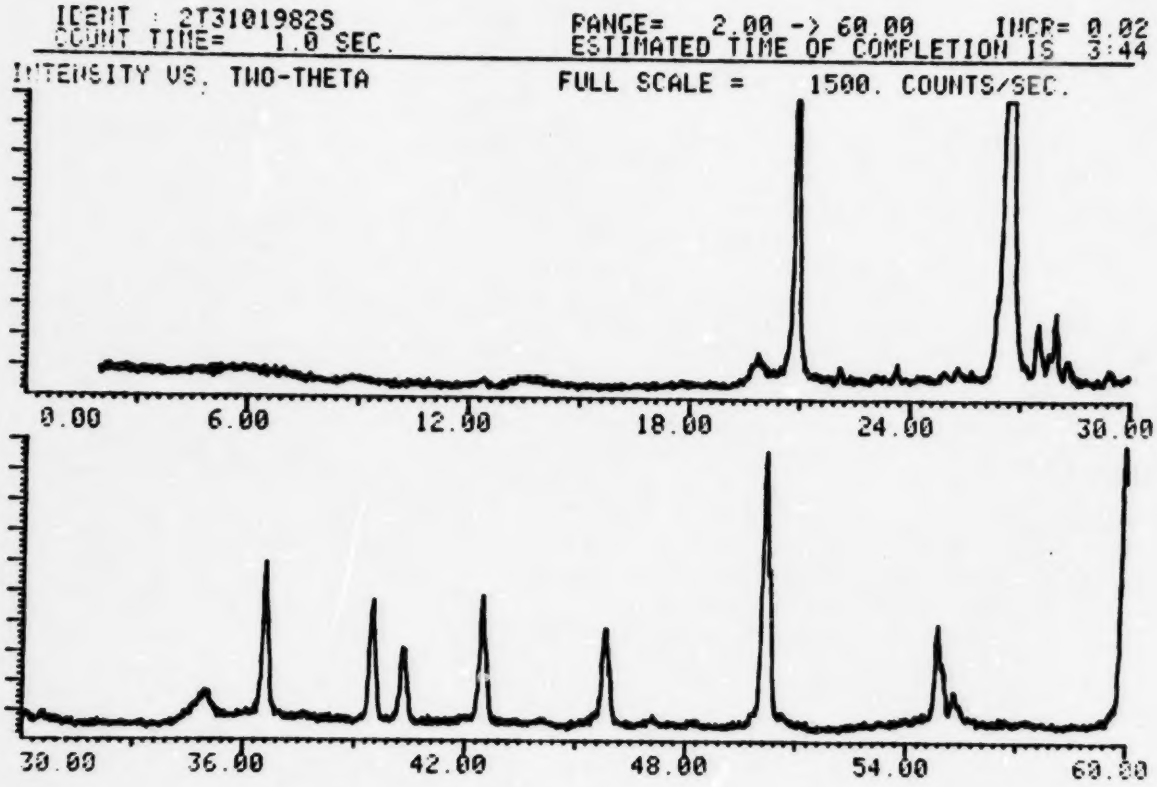


```
IDENT : BT3101982S                    RANGE=   2.00 -> 60.00      INCR= 0.02
COUNT TIME=   1.0 SEC.                ESTIMATED TIME OF COMPLETION IS  2:34
INTENSITY VS. TWO-THETA               FULL SCALE =     1500. COUNTS/SEC.
```

(continued)

Reproduced from best available copy.

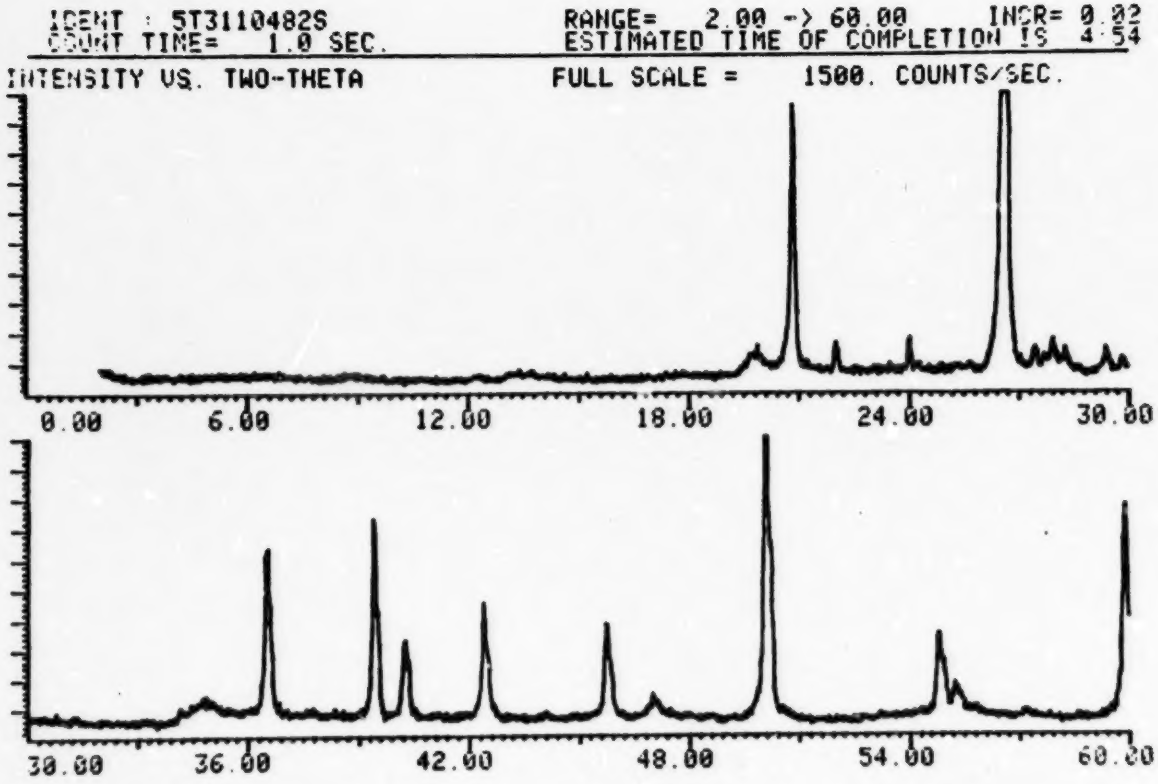
APPENDIX F (continued)



(continued)

Reproduced from best available copy.

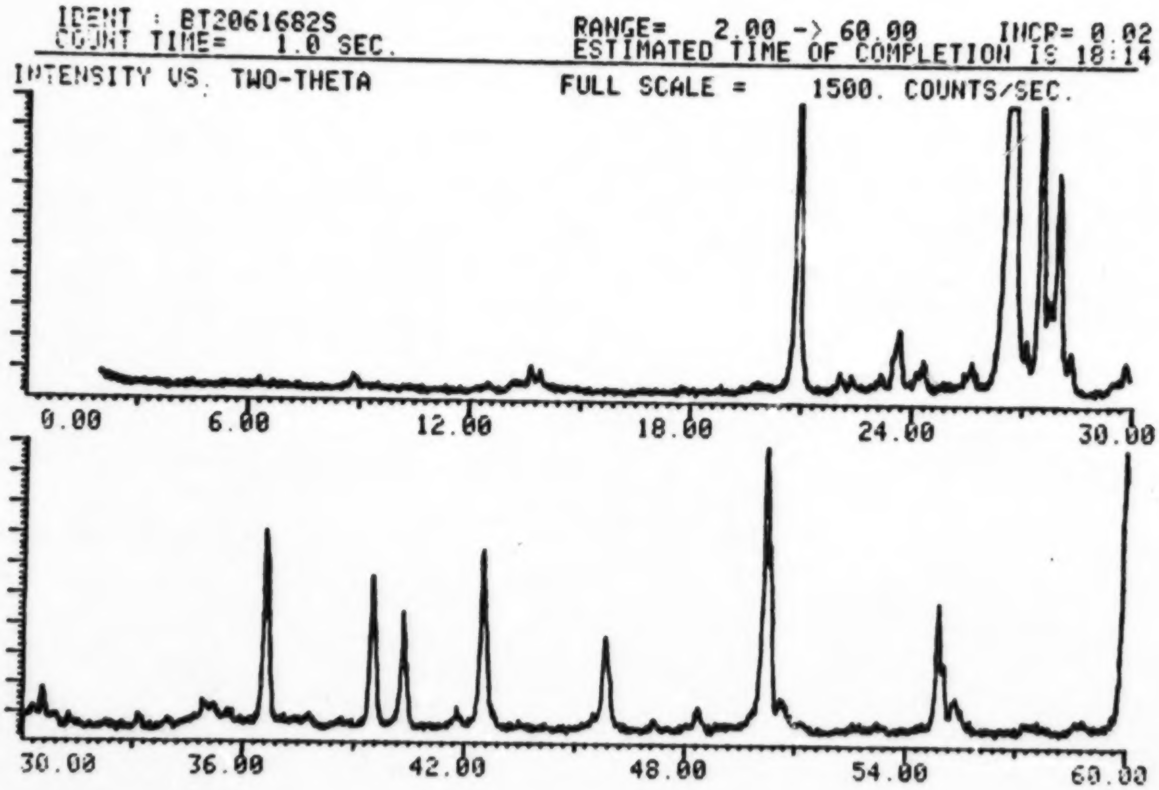
APPENDIX F (continued)



(continued)

Reproduced from
best available copy.

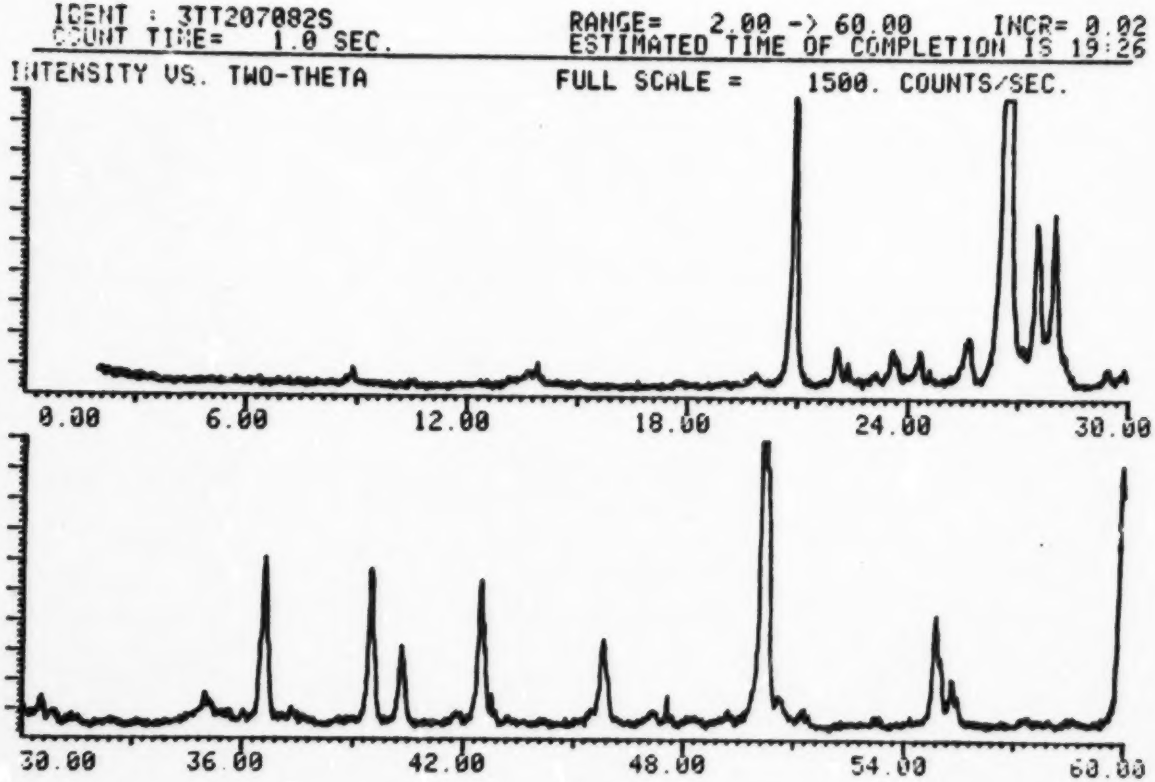
APPENDIX F (continued)



(continued)

Reproduced from best available copy.

APPENDIX F (continued)



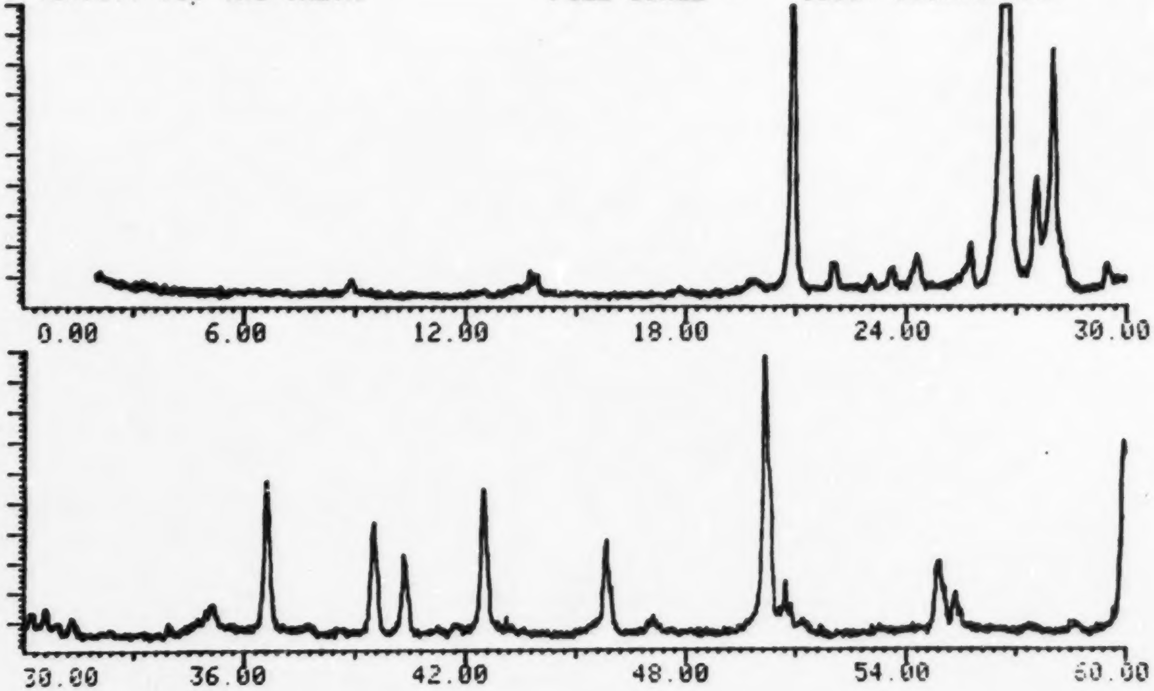
```
IDENT : 3TT207082S                  RANGE=   2.00 -> 60.00      INCR= 0.02
COUNT TIME=   1.0 SEC.              ESTIMATED TIME OF COMPLETION IS 19:26
INTENSITY VS. TWO-THETA             FULL SCALE =    1500. COUNTS/SEC.
```

(continued)

Reproduced from best available copy.

APPENDIX F (continued)

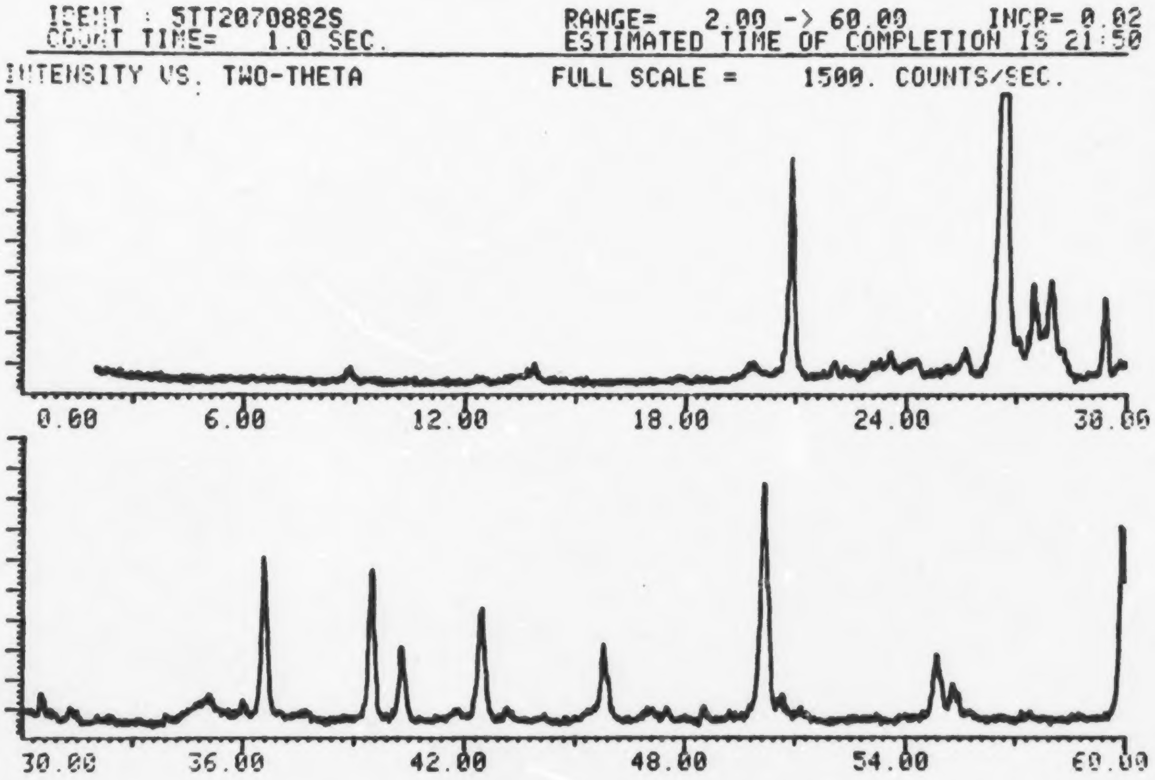
IDENT : 4TT2070882S   RANGE= 2.00 -> 60.00   INCP= 0.02
COUNT TIME= 1.0 SEC.   ESTIMATED TIME OF COMPLETION IS 20:38
INTENSITY VS. TWO-THETA   FULL SCALE = 1500. COUNTS/SEC.



(continued)

Reproduced from best available copy.

APPENDIX F (continued)



```
IDENT : 5TT20708825            RANGE=   2.00 -> 60.00      INCR= 0.02
COUNT TIME=   1.0 SEC.         ESTIMATED TIME OF COMPLETION IS 21:50
INTENSITY VS. TWO-THETA         FULL SCALE =     1500. COUNTS/SEC.
```

Reproduced from best available copy.